

**“STUDIES ON BIOLOGY, MASS
MULTIPLICATION AND MANAGEMENT OF
COTTON MEALYBUG, *Phenacoccus solenopsis*
(TINSLEY) AND ITS PARASITOID”**

A

Thesis submitted to the

**MAHATMA PHULE KRISHI VIDYAPEETH,
RAHURI - 413 722, DIST. AHMEDNAGAR,
MAHARASHTRA, INDIA**

For the award of the degree of

DOCTOR OF PHILOSOPHY (AGRICULTURE)

in

AGRICULTURAL ENTOMOLOGY

by

SANDIP ANANDA LANDGE

(Reg. No. 07/14)

DEPARTMENT OF AGRICULTURAL ENTOMOLOGY

**POST GRADUATE INSTITUTE
MAHATMA PHULE KRISHI VIDYAPEETH,
RAHURI - 413 722, DIST. AHMEDNAGAR,
MAHARASHTRA, INDIA**

2014

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MAHARASHTRA, INDIA**

in partial fulfillment of the requirements for the degree

of

DOCTOR OF PHILOSOPHY (AGRICULTURE)

in

AGRICULTURAL ENTOMOLOGY

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2014

CANDIDATE'S DECLARATION

I hereby declare that this thesis or part of
thereof has not been submitted
by me or any other person to any
other University or Institute
for a Degree or
Diploma.

Place : MPKV, Rahuri
Date :24/03/2014

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CERTIFICATE

This is to certify that the thesis entitled “**STUDIES ON BIOLOGY, MASS MULTIPLICATION AND MANAGEMENT OF COTTON MEALYBUG, *Phenacoccus solenopsis* (TINSLEY) AND ITS PARASITOID,**” submitted to the Faculty of Agriculture, Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahmednagar, Maharashtra State, for the award of the degree of **DOCTOR OF PHILOSOPHY (AGRICULTURE)** in **AGRICULTURAL ENTOMOLOGY**, embodies the results of a *bona fide* research carried out by **MR. SANDIP ANANDA LANDGE**, under my guidance and supervision and that no part of the thesis has been submitted for any other Degree or Diploma.

The assistance and help received during the course of this investigation have been acknowledged.

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ACKNOWLEDGEMENT

I wish to place on record my heartiest gratitude to Dr. V.D. Kale, Ex-Professor, Department of Agril. Entomology, MPKV, Rahuri and the Chairman of Advisory Committee for suggesting the problem and his valuable guidance in the pursuit of the research work and help in the preparation of the thesis manuscript.

I enroll my esteem and in estimate with great respect to the advisory committee members Dr. A.G. Chandele, Ex-Head, Department of Agril. Entomology; Dr. J.R. Kadam, Ex-Professor of Agril. Entomology; Dr. R.R. Perane, Cotton Pathologist, Cotton Improvement Project, MPKV, Rahuri for their valuable guidance and kind co-operation at appropriate times during the course of studies.

I sincerely thanks to Dr. H.G. More, Ex-Dean, MPKV, Rahuri and Dr. R. S. Patil, Director of Research, MPKV, Rahuri for providing necessary facilities for successful completion of my research work.

My sincere and heartfelt gratitude to Dr. S. S. Jadhav, Head, Department of Agril. Entomology, Dr. M. D. Dethe, Ex-Head, Department of Agril. Entomology, Prof. P.K. Dharne, Associate Dean, College of Agriculture, Dhule and Dr. S.K. Patil, Assistant Professor of Entomology, for their inspiring guidance during the course of investigations.

I express my deep sense of gratitude to Dr. S.B. Kharbade, Professor of Entomology, Dr. S.M. Pokharkar, Professor of Entomology, Dr. R.V. Nakat, Associate Professor of Entomology; Dr. S.R. Kulkarni, Associate Professor of Entomology; Dr. C.S. Patil, Residue Analyst; Dr. C.A. Nimbalkar, Associate Professor of Statistics Dr. U.K. Kadam, Assistant Professor of Entomology,

Dr.Y.S.Saindane, Assistant Residue Analyst, Dr.B.V.Deore, Assistant Residue Analyst, for their kind cooperation and timely help during the studies.

I am grateful to Mr. S.M. Gangurde, Dr. Ganesh Bansode, Mr. A.J.Amale, Mr. R.V. Kadu, Ajay Hajare, Mr. S.D. Wale, Mr. D.R. Autade, Mr. V.C. Girhe, Mr. Pardeshi, Mr. V.D. Shinde, Mrs. Chemate and Miss. Shinde for their kind help during the course of investigation.

I express my thanks to all the authers, past and present whose literature has been cited.

Words are not enough to express my sincere and heartily gratitude to my beloved parents Bhau and Bai and Anna, Nana the prime architects of my career. Immense thanks to my elder brothers, Dadasaheb, Vijay and relatives for their moral support to achieve this goal.

I owe my gratitude to my wife Mrs. Manisha for her endurance and understanding which have been quite overwhelming. Without their persuasions and support, this degree programme would have not been completed.

Place : MPKV, Rahuri
Date : 24/03/2014

(S. A. Landge)

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ABBREVIATIONS

a.i.	: Active ingredient
@	: At the rate of
cm	: Centimetre
C.D.	: Critical difference
CFU	: Colony Forming Unit
CRD	: Completely Randomized Design
DAS	: Days After Spray
EC	: Emulsifiable concentrate
e.g.	: <i>exempli gratia</i> or for example
<i>et al.</i>	: <i>et alii</i> (and other)
<i>etc.</i>	: <i>Et cetera</i> and so on
Fig.	: Figure
g	: Gram
ha	: Hectare (s)
h	: Hour
i.e.	: <i>id est</i> (that is)
IGR	: Insect growth regulator
kg	: Kilogram (s)
L	: Litre
LC ₅₀	: Median lethal concentration of a toxicant that kills 50 % of the organisms exposed to it
Ltd.	: Limited
mg	: Milligram (s)
ml	: Milimetre (s)
Min	: Minute (s)
mm	: Milimeter
No.	: Number
μ	: Micron

μg	: Microgram (s)
μm	: Micro meter
RBD	: Randomized Block Design
RH	: Relative Humidity
qt	: Quintal
SC	: Soluble Concentrate
S.D.	: Standard deviation
S.E.	: Standard Error
SG	: Soluble Granule (s)
SL	: Soluble Liquid
sp	: Species
<i>viz.,</i>	: <i>videlicet</i> (namely)
WDG	: Water Dispersible Granule (s)
WG	: Wettable Granule (s)
Wt	: Weight
$^{\circ}\text{C}$	: Degree Celsius
=	: Equal to
>	: Greater than
<	: Less than
/	: Per
%	: Per cent
$\pm$	: Plus or minus

ABSTRACT

**“STUDIES ON BIOLOGY, MASS MULTIPLICATION AND
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A candidate for the degree of

DOCTOR OF PHILOSOPHY (AGRICULTURE)

MAHATMA PHULE KRISHI VIDYAPPETH,

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2013

Research Guide :	Dr. V. D. Kale
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The present investigations were undertaken at Department of Agricultural Entomology, Post Graduate Institute, Mahatma Phule Krishi Vidyapeeth, Rahuri to study biology, mass multiplication and management of cotton mealybug, *Phenacoccus solenopsis* and its parasitoid *Aenasius bambawalei* in the laboratory at temperature 25 ± 2 °C and 65 ± 5 RH and also under field condition.

Biology studies of *P.solenopsis* on potato sprouts indicated that the pest reproduced parthenogenetically. Adult female was larger in size (3.90 ± 0.06 mm in length and 2.05 ± 0.04 mm in width) as compared to male which was smaller in size (1.10 ± 0.06 mm in length and 0.20 ± 0.02 mm in width). The male was short lived with an adult life of 2.08 ± 0.59 days, while female lived longer (17.16 ± 2.33 days). On an average, male and female completed their life cycle in 21.30 ± 4.33 and 36.84 ± 5.87 days, respectively. Mealybug delivered 4 to 7 ovisacs during its life span in which 312 to 860 eggs with a mean of 594.84 ± 64 were deposited and male to female sex ratio was 1:3.

A.bambawalei is a solitary endoparasitoid and female parasitoid was larger in size (1.81 ± 0.21 mm in length, 0.78 ± 0.05 mm

ABSTRACT contd..

in width and 0.84 ± 0.05 mm head width) as compared with male which was smaller in size (1.20 ± 0.12 mm in length, 0.39 ± 0.04 mm in width and 0.44 ± 0.05 mm in head width). Pupal period of *A.bambawalei* ranged from 4 to 7 days in male and 6 to 10 days in female. The male was short lived with an adult longevity of 6.49 ± 1.16 days, while female lived longer (27.11 ± 5.31 days). On an average, male and female completed their life cycle in 17.79 ± 3.17 and 40.27 ± 7.52 days, respectively. Adult female parasitoid parasitized 25 to 155 mealybugs during entire life cycle and male to female sex ratio was 1:2.

Among different hosts used, maximum nymphs (87.50%) of mealybug reached to adult stage on potato sprouts followed by *Hibiscus* (80.83%) and cotton (79.16%). Total nymphal period was minimum (15.82 ± 2.66 days) on potato sprouts as compared to cotton (12.48 ± 1.68 days) and *Hibiscus* (17.66 ± 2.41 days). Oviposition and post-oviposition period was maximum i.e. 14.28 ± 1.65 and 2.96 ± 0.68 days on potato sprouts as compared to 10.44 ± 1.94 and 2.64 ± 0.49 days on cotton and 12.40 ± 1.68 and 2.84 ± 0.37 days on *Hibiscus*. Potato sprouts had high mean fecundity (594.84 ± 163.65) followed by *Hibiscus* (492.8 ± 110.92) and cotton (481.6 ± 92.32). Sex ratio was 1:3 on cotton, 1:3 on potato sprouts and 1:2.2 on *Hibiscus*.

The development rates of *P.solenopsis* were studied at different constant temperatures i.e. 25 ± 2 , 27 ± 2 , 30 ± 2 and 32 ± 2 °C. The fecundity was maximum, 487.60 ± 92.34 at 25 °C and found to be decreasing with increasing temperature. The total nymphal period was high in all instars at 25°C (16.44 ± 2.74 days) followed by 27°C (16.25 ± 2.29 days), 30 °C (15.75 ± 1.83 days) and 32°C (16.02 ± 2.36 days).

The maximum percentage of parasitization (91.20%) by *A.bambawalei* was observed on 3rd instar followed by adult host mealybug (81.20%), 2nd instar mealybug (31.00%) and no

ABSTRACT contd..

parasitization was recorded on 1st instar host mealybug. The male to female sex ratio was more on adult host (1:2) followed by subsequent instars of host *i.e.* 1:1.5 and 3:2.0 on 3rd and 2nd instars, respectively.

Development rates of *A.bambawalei* at different constant temperatures *viz.* 25±2, 27±2, 30±2 and 32±2 °C were also studied. The mean fecundity (parasitized mealybugs) was maximum, 88.36±33.80 at 25±2 °C and found to be decreasing with subsequent increasing temperature. The total larval period was high (6.0 days) at 25±2 °C followed by decreased larval period with increasing temperatures of 27, 30±2 and 32±2 °C. The oviposition and post-oviposition period was maximum (24.72±4.37 and 3.27±1.03 days) at 25±2 °C and was found to be less in subsequent temperatures. However, sex ratio was 1:2 at 25±2 and 27±2 °C, while it was 1:1.5 at 30±2 and 32±2 °C.

Toxicity of different insecticides to parasitoid *A.bambawalei* was evaluated, no mortality of *A. bambawalei* was observed in *Verticilium*, *Beauveria*, *Metarrhizium* and buprofezin treatments after 1, 3, 6, 12 and 24 h after exposure to treated jars both in female and male but moderate to high mortality of both female and male parasitoids was noticed after 1h in NSKE (50.00%), clothianidin (85.00%), imidacloprid (82.50%) and thiamethoxam (85.00%). However, 42.50 per cent mortality of female and 45.00 per cent of male was observed in neem oil which was slightly high. Dichlorvos, profenophos, triazophos and chlorpyriphos caused 100 per cent mortality within 1 h in both sexes.

Field surveys during *Kharif*, 2009 on cotton and associated weeds undertaken in September, October and November months, indicated maximum infestation of mealybug in October month and it was highest on *Hibiscus* (61.50%) followed by *Mesta* (60.50%), *Gossypium* (28.50%) and *Acalypha* (28.00%); whereas, it was minimum on *Xanthium* (5.50%). As regards parasitization, the highest parasitization (7.89%) of mealybug by *A. bambawalei* was

ABSTRACT contd..

found on *Hibiscus* followed by Mesta (7.69%) and *Parthenium* (5.48%).

Efficacy of insecticides and other biopesticides against mealybug was evaluated using thirteen insecticides and biopesticides during 2008 and 2009. The pooled data showed that before initiation of spray treatment population of mealybug ranged from 98.03 to 115.36 mealybugs/ 10 cm apical shoot. On 3, 7 and 10 days after spray, profenophos 50 EC @ 1500 ml ha⁻¹ recorded lowest mealybug population 33.88, 17.00 and 13.99 mealybugs/10 which was at par with the population found in chlorpyrifos 20 EC @ 1500 ml ha⁻¹ (36.27, 19.35 and 18.58 mealybugs/10 cm). Next best treatments were dichlorvos 76 EC @ 1000 ml ha⁻¹ followed by triazophos 40 EC @ 625 ml ha⁻¹ and both the treatments were at par with each other. Next promising treatments were imidacloprid 17.8 SL @ 200 g ha⁻¹ followed by clothianidin 50 WDG @ 150 g ha⁻¹ and were at par with each other. The treatments *V. lecanii* @ 2000 g ha⁻¹, *M. anisopliae* @ 2000 g ha⁻¹, *B. bassiana* @ 2000 g ha⁻¹ and buprofezin 25 SC @ 1250 ml ha⁻¹ lowered the pest population effectively upto 14 DAS. Whereas the treatments neem oil @ 2000 ml ha⁻¹, NSKE 5% @ 25000 g ha⁻¹, dichlorvos 76 EC @ 1000 ml ha⁻¹, clothianidin @ 150 g ha⁻¹, imidacloprid @ 200 ml ha⁻¹, thiamethoxam @ 200 g ha⁻¹ and triazophos @ 625 ml ha⁻¹ lowered the pest population upto 10 DAS.

Profenophos, buprofezin and chlorpyrifos were found to be effective for the management of mealybugs on cotton in both *Kharif*, 2008 and *Kharif*, 2009. Profenophos 50 EC, buprofezin 25 SC and chlorpyrifos 20 EC recorded maximum net gain of Rs. 35,760/-, Rs. 32,272/-, and Rs. 32,550 ha⁻¹ and Rs. 43,600/- and Rs.42,415/-, Rs. 42,410/-, respectively over control.

1. INTRODUCTION

Cotton (*Gossypium* spp.), popularly known as the 'white gold', is one of the largely cultivated cash crops grown all over the country. It exerts considerable influence on Indian Economy. Introduction of *Bt* cotton for commercial cultivation in India has become a boon to the cotton growing farmers since 2002 and eventuated in good yields with very good returns. *Bt* cotton clearly appears to have been playing a key role in cotton production and productivity. In India, cotton contributes almost 85 per cent of total fibre consumed in textile industry. Area under cotton in India was 12.20 million hectares and production 27 million bales with an average productivity of 482 kg ha⁻¹. In Maharashtra, the cotton crop is extensively cultivated over an area of 40.95 lakh ha both under irrigated and rainfed conditions with productivity of 310.32 kg ha⁻¹ and production of 74.75 lakh bales (Anonymous, 2012).

Second generation *Bt* cotton has given solution to the bollworm complex to the larger extent but at the same time it is susceptible to most of the sucking pests viz., thrips, (*Thrips tabaci* L), leaf hoppers (*Amrasca biguttula biguttula* Ishida), aphids (*Aphis gossypii* Glover), whitefly (*Bemisia tabaci* Gennadius) and dusky cotton bug (*Oxycarenus hyalinipennis* Costa). In recent past, mealybug has been reported as serious pest on cotton from different parts of the country (Nagrare *et al.*, 2009). In the current decade, the trend of increased build up of various mealybug species in crop plants and in the wild plants is observed mainly due to certain abiotic changes in climate and environment. Mealybug species viz., *Phenacoccus solenopsis* Tinsley, *Phenacoccus solani* Ferris and *Maconellicoccus hirsutus*

(Green) have been recorded on cotton in India. Among them *P. solenopsis* is a major and wide spread species in the country (Nagrare *et al.*, 2009). The appearance of exotic mealybug, initially reported as Solanum mealybug, *Phenacoccus solani* Ferris (Gautam, 2007; Gautam *et al.*, 2007; Gautam, 2008a ; Suresh and Kavitha, 2007) was later identified as Solenopsis mealybug, *Phenacoccus solenopsis* Tinsley (Thomas and Ramamurthy, 2008). Hodgson *et al.* (2008) reported that the mealybug species currently causing wide spread damage to cotton on the Indian Sub-continent is *P. solenopsis* and morphological variations across the locations are seasonal and environmentally induced. There is no record of *P. solenopsis* being indigenous to India, hence is supposed to be exotic and a threat to Indian agriculture (Gautam, 2007; 2008a, 2009). Recent flare up of mealybug, *P. solenopsis* on several crops of economic importance and its devastating effect on both *Bt* cotton and conventionally grown cotton hybrids in Maharashtra, Delhi, Gujarat, Haryana, Punjab, Uttar Pradesh and many other places (Dhawan *et al.*, 2007; Gautam, 2007; Gautam *et al.*, 2007; Gautam, 2008a; Tanwar *et al.*, 2007; Bhosle *et al.*, 2009) warrants immediate attention of researchers.

Mealybug, *P. solenopsis* (Hemiptera: Pseudococcidae) is a soft bodied insect pest of field, ornamental and fruit trees worldwide and is known to be cryptic in nature. It was described originally from the U.S. in 1898 and remained there until 1992. Later, it was reported in Central America, the Caribbean and Ecuador (Williams *et al.*, 1992 and Ben-Dov, 2004). Its occurrence in other areas is not surprising because insects that were previously found in a particular area are now occurring in other new geographic areas where they are believed to have been

introduced. Its existence was reported for the first time in Brazil on tomato plant (Mark and Penny, 2005). This mealybug has been found previously on a relatively wide variety of host plants including species in economically important families such as Solanaceae, Cucurbitaceae and Fabaceae. In India, cotton mealybug is known to be introduced from Pakistan since, the three largest cotton growers in Asia are China, India and Pakistan which share common borders that make them vulnerable to insect and disease transfers (Anonymous, 2006). Later it has spread to cotton crop in some districts of Punjab but in 2007 it has spread throughout major cotton growing districts and caused 30 to 40 per cent loss in cotton yield (Dhawan *et al.*, 2007). Severe economic damage to *G. hirsutum* was reported in 2007 in four major cotton growing districts of Punjab, two districts of Haryana, and low to moderate damage in parts of Maharashtra, Tamil Nadu and Andhra Pradesh (Dharajyoti *et al.*, 2008 and Dhawan *et al.*, 2008). Nearly 2000 acres of cotton was destroyed by mealybug and over 100 acres of infested cotton was uprooted in Bhatinda (Punjab). The estimated loss ranged from US\$ 400000 to 500000 in North India alone (Goswami, 2007).

According to Saini and Ram (2008), *P. solenopsis* is a sap sucking pest and once established on a plant; often remains there till the attacked plant dries up. When the attack is in the vegetative phase, the plant remains stunted, the attacked parts gradually dry up. However, when the attack is in the reproductive phase, there is no further production of fruiting bodies on attacked branch. Already formed buds, flowers and young bolls dry up while grown up bolls open prematurely. Pest spreads to the nearby healthy plants from attacked plants and

gradually large patches of dried cotton plants bearing prematurely opened bolls appear in the field.

The mealybugs feed on phloem tissue, removing plant sap and causing leaves to distort yellow and dry. They feed on all parts of a plant, particularly new growth. Yellowing of leaves or leaf drop is the symptom of its infestation. They can be observed particularly on growing tips or on leaves that join stems or along leaf veins. Like the aphids, mealybugs also excrete the honeydew over plant surfaces and sometimes a secondary fungus called black sooty mould grows on plant and reduces the quality of the lint. The change of pesticide usage with new technological development, introduction of transgenic insect tolerant plants into farming ecosystem and favorable weather conditions in recent years have resulted in this new pest problem. Thus mealybug, hitherto unknown as pest on cotton, has emerged as a key pest and assumed as a great production threat. Management of mealybug is difficult due to its wide host range, presence of waxy coating on the body and high reproductive potential. However, the crawler stage is the most fragile and easily controllable stage in its life history. Recently some organophosphates, insect growth regulators (IGRs) and bio-pesticides have been recommended for the control of mealybug (Suresh *et al.*, 2010). For better management of cotton mealybug, it is necessary to understand its life history, so as to target the pest at its weak stage of life span. The information on economic threshold level of mealybug and losses caused by them is also lacking. Evaluation of new and safer pesticide molecules along with conventional pesticides against mealybug is, therefore, the need of the hour. Further, there is an immediate need to develop economically feasible and viable integrated pest management

strategy to combat the mealybugs and other insect pests on cotton.

The parasitoid *Aenasius bambawalei* Hayat, reported as effective biological control agent of cotton mealybug, appears to be a sustainable control measure. This parasitoid is a primary, solitary endoparasitoid; and one adult parasitoid is produced from each parasitized mealybug with entire immature development occurring within the host. This parasitoid was observed in mealybug affected cotton area of Ahmednagar district of Maharashtra. This parasitoid can be explored with a view to manage cotton mealybug effectively. Keeping the above points in view, the detailed investigation against mealybug on cotton was undertaken with the following objectives:

1. To study the biology of cotton mealybug, *Phenacoccus solenopsis* (Tinsley) and its parasitoid.
2. Mass production of cotton mealybug as host for parasitoid *A.bambawalei*.
3. Multiplication of parasitoid of cotton mealybug.
4. Evaluation of different chemical insecticides and biopesticides for the management of cotton mealybug, *P. solenopsis*.

2. REVIEW OF LITERATURE

Cotton mealybug *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae) is a recently introduced species in India, due to polyphagous nature, the pest has been reported to feed on large number of host plants. Therefore, literature available on all parameters is reviewed.

2.1 Biology of mealybug, *P. solenopsis*

McKenzie (1967) reported detailed account of morphological characters of adult *P. solenopsis* female as under; body oval, often quite large (5 mm); somewhat rounded in lateral view; dark green almost black; legs red, covered with thin, white, mealy wax, with dark dorsosubmedial bare spots on intersegmental areas of thorax and abdomen, these areas forming one pair of dark longitudinal lines on dorsum; laid eggs in ovisacs. Ovisacs absent from dorsum but well developed ventrally; with 18 pairs of lateral wax filaments, posterior pairs longest; surface of lateral filaments was rough.

Singh and Ghosh (1970) reported life history of *Macconellicoccus hirsutus* on Mesta. According to them incubation period occupied 6 to 7 days and nymphal stage occupied 22 days. Pre oviposition period lasted for 3-5 days. Only parthenogenic oviposition was observed.

Ghose (1972) noted that *M. hirsutus* was active during winter without hibernation but was most active in March to October. He made detailed investigation of *M. hirsutus* on roselle. The nymphal development in male and female was completed in 10 to 19 and 11 to 17 days, respectively. Life cycle occupied 23 to 29 days.

Mani (1986) studied the biology of *M. hirsutus* and reported incubation period of 5.15 days. The females had three

while, the males four nymphal instars. The nymphal development in male and female was completed in 24.85 and 26.31 days, respectively when reared on pumpkin fruits in the laboratory. Its fecundity ranged from 386 to 510 eggs.

According to Mishra *et al.* (2004) the duration of first instar nymph in other species of *Phenacoccus* has been reported to be 5-14 days in *P. bengalensis*. Preoviposition and oviposition period ranged from 11-17 and 7-11 days, respectively.

Nakahira and Arakawa (2006) studied variation in the life cycle of *P. solani* (an invasive species closely resembling *P. solenopsis*) at 20, 25 and 30 °C in a photoperiod of 16 hours light: 8 hours darkness at Kochi University, Japan. They found that the total developmental periods of the immature stages and the pre-reproductive period of the adults decreased significantly with increased temperatures, and the survival rates of the immature stages were high at all temperatures. Duration of first instar was 12.6, 7.2 and 5.1 days at 20, 25 and 30 °C, respectively. Second instar nymph of female *P. solani* was 8.8, 5.8 and 4.2 days at 20, 25 and 30 °C, respectively. Third instar nymph of female *P. solani* was 12.1, 6.1 and 4.2 days at 20, 25 and 30 °C, respectively. Preoviposition period was 26.3, 14.8 and 13.0 days at 20, 25 and 30 °C, respectively. However, the adults lived significantly longer at 20 °C than at higher temperatures, and the number of offspring produced per female was significantly lower at 30 °C than at lower temperatures. The net reproductive rate and the intrinsic rate of natural increase of *P. solani* were highest at 25 °C.

Gautam *et al.* (2007) recorded the reproductive potential of *P. solani* based on the crawler production by gravid female. Among various host plants, the highest crawler production was recorded on sunflower (313.6 crawlers), followed by *Hibiscus* (284.2), okra (250.8), cotton (232), *Lantana* (219.6), tomato (216.7), chilli (198.2), *Parthenium* (191), wild jute (170.4), amaranthus (159.2), carpet grass (154.2) and *Chenopodium* (125.6).

Tanwar *et al.* (2007) reported that reproduction in *P. solenopsis* was mostly parthenogenic but some species such as *M. hirsutus* are bi-parental. The female lays eggs in an egg sac of white wax, usually in clusters on the twigs, branches, or bark of the host plant but sometimes on the plant's leaves and terminal ends. Each egg sac may contain as many as 600 eggs, majority of which are female resulting in explosive outbreak. Eggs are minute, varying from 0.3 to 0.4 mm in length. There are three nymphal instars in female and four in males which last for 22-25 days. The last instar of the male was an inactive stage with wing buds within a cocoon of mealy wax.

Akintola and Ande (2008) determined life history as well as the instar duration in days and documented for each developmental stage. There were three nymphal stages which lasted for 6, 8 and 10 days in female and the adult stages. Duration of first instar nymph was 6 days while, second instar 8 days. The total numbers of days from egg to adult were 37 days. Adult longevity of *P. solenopsis* female was 37 days.

Abbas *et al.* (2008) reported that *Phenacoccus solenopsis* shown to be sexually dimorphic, short lived, winged males and long-lived, wingless, larviform females. It was found to reproduce sexually, producing live young ones instead of laying eggs. The eggs are retained in the body until they are ready to hatch, a phenomenon known as ovoviviparity (Arif *et al.*, 2009; Arif *et al.*, 2008; Yousuf *et al.*, 2007).

Hodgson *et al.* (2008) found that *P. solenopsis* first instar nymphs were oval measuring 710 to 730 µm in length and 359 to 380 µm in width. Adult longevity of male *P. solenopsis* lasted for few hours to 3 days. Reproduction of *P. solenopsis* was bisexual and ovo-viviparous.

Katke and Balikai (2008) investigated the biology of the grape mealybug *M. hirsutus* on sprouted potatoes during

winter 2005-06 and summer 2006. During winter season, the duration from egg to adult emergence occupied by the female and male was 29.1 ± 1.29 and 26.5 ± 1.62 days, respectively. In summer season, the female and male live for 26.4 ± 1.57 and 24.6 ± 1.53 days, respectively. The longevity of female ranged from 12-15 days with a mean of 14.3 ± 0.85 days, whereas male lives 3 to 4 days with a mean of 3.4 ± 0.46 days during winter season. According to Mohammad (2008), *P. solenopsis* nymphs feed and develop into adults in approximately 30 days. The female mealybug produces 10-15 generations per year in colonies of 500 to 600 eggs. The insect has a life cycle of 24 to 30 days.

Aheer *et al.* (2009) made investigation on biology of *P. solenopsis* on China rose in laboratories of Entomological Research Institute, AARI, Faisalabad (Pakistan) during 2007. They observed that *P. solenopsis* laid eggs in ovisacs and were orange in colour, elongate in shape and measured 0.45 mm in length and 0.20 mm in width. Incubation period of *P. solenopsis* eggs ranged from 30 to 45 minutes. There were three nymphal stages in case of female and two in male. First instar crawlers of *P. solenopsis* were yellowish green in colour measuring 0.5 mm in length and 0.25 mm in width. Duration of first instar nymph ranged from 7 to 9 days. Second instar nymph of female was 3 to 4 days and that of male 4 to 9 days. Third nymphal female of *P. solenopsis* lasted for 6.5 to 8 days. They further observed that male started forming pupa after second instar nymph. Pupal stage of this pest measured 1.80 mm and 0.50 mm in length and width, respectively. Male *P. solenopsis* started forming pupa after completion of second instar, which lasted for 6.5 to 9 days. The pupal stage in female was absent. Adult male of *P.*

solenopsis was winged and body length and width 1.0 and 0.20 mm, respectively and lived for 2 to 3 days and female 45 to 85 days. Total life cycle of male and female lasted for 19.5 to 30 and 61.5 to 106 days, respectively. Reproduction of *P. solenopsis* was bisexual and ovo-viviparous.

Dhawan and Saini (2009) observed that in first instar body measured 0.73×0.47 mm. Duration of second instar female nymph of *P. solenopsis* was 8 days. Adult longevity of *P. solenopsis* male and female ranged from 1 to 2 and 13 to 17 days, respectively. Total life cycle of male and female ranged from 16 to 23 and 27 to 38 days, respectively.

Dhawan and Saini (2009) reported that eggs of *P. solenopsis* were pale yellow in colour and oval in shape and measured 0.37×0.17 mm. The first instar nymphs of *P. solenopsis* were oblong in shape and yellow in colour and devoid of mealy scale cover. Duration of first instar nymph ranged from 4 to 6 days. Third instar was dark yellow in colour, oblong in shape and measured 2.4 mm in length and 1.2 mm in width. Adult female was oblong, yellow in colour and wingless. Further, they reported that the adult female was 4.4 mm in length and 2.9 mm in width. Fecundity of *P. solenopsis* varied from 270 to 340 crawlers per female.

Rishikumar *et al.* (2009) studied the life history of *P. solenopsis* in Sirsa. The number of ovisac varied on an average from 2-4 per female. The mealybug was found as a prolific breeder with mean reproductive potential based on crawler production per female in a range from 289 to 517 on cotton. The numbers of nymphal stages recorded were 3, both in female and male (two nymphal instars and a cocoon). Both 1st and 2nd instar mealybug lacked mealy wax secretion. The first instar mealybug / crawlers lacked permanent feeding site because of high

motility. The total nymphal duration in case of male and female was 13 to 15 days and 14 to 19 days, respectively. In the last instar female nymph had the appearance of mealy wax scale covering entire body but in male secretion of cocoon (puparia) was observed leading to emergence of short lived winged males with two long waxy caudal filaments at the posterior end. The longevity of males and females was 1 to 1.8 days and 13 to 16 days, respectively.

Patel *et al.* (2010) reported that the eggs were creamy yellow in colour, oblong in shape and measured 0.37 mm in length and 0.19 mm in width. Second instar of *P. solenopsis* was light green in colour and incubation period was 35 to 60 minutes in the laboratory condition. The measurement of second instar nymphs has been reported to be 0.66 to 0.87 mm. Preoviposition, oviposition and postoviposition period of *P. solenopsis* varied from 8 to 9, 16 to 18 and 9 to 10 days, respectively. Fecundity ranged from 400 to 700 eggs when reared on cotton leaves in the laboratory. Female adult longevity was reported from 32 to 35 days and that of male from 7 to 10 days.

Patel *et al.* (2010) noted that the length and width of first instar nymphs ranged from 0.39 to 0.42 mm and 0.19 to 0.22 mm, respectively, and duration of first instar nymph ranged from 6 to 7 days. Duration of second instar nymph of *P. solenopsis* varied from 4 to 6 days. Third instar lasted for 4 to 6 days. They further suggested that male and female nymph of *P. solenopsis* could be distinguished from the third instar onwards. Male started forming pupa after completion of third instar nymph which lasted for 6 to 7 days.

Vennila *et al.* (2010) studied the biology of the mealybug *P. solenopsis* on cotton under laboratory conditions. The developmental period from immature crawler to adult stage was greater for males (18.7 ± 0.9 days) compared to females (13.2 ± 1.8 days), probably due to the additional molt to pupal stage in males. Survival of second instars was lower (45.5%) than first

and third instar (71.4%) and fecundity ranged from 128 to 812 crawlers. The reproductive period lasted 30.2 ± 8.2 days. Adult females lived 42.4 ± 5.7 days, while male 1.5 ± 0.1 days.

Prasad *et al.* (2011) who reported that in September month highest infestation of mealybug and parasitization of *Aenasius bambawalei* was observed in roadside fields adjacent to cotton followed by cotton fields adjacent to crop fallows.

Satpute *et al.* (2011) studied the biology of mealybug *Phenacoccus solenopsis* (Tinsley) on different hosts under laboratory condition and it was found that *P. solenopsis* reproduced parthenogenitically with ovoviviparity. Female had three nymphal instars whereas the male also possesses a pupal stage. The total developmental period of female nymphs was 22.5, 26 and 23.5 days on cotton, *Hibiscus* and sprouted potato, respectively. The longevity of an adult female varied from 10 to 13 days on cotton, 11 to 14 days on *Hibiscus* and 11 to 14 days on sprouted potatoes. The fecundity was more when the mealybugs were fed on *Hibiscus* than the other two hosts.

2.2 Biology of mealybug parasitoid, *A. bambawalei*

Survey conducted by Tanwar *et al.* (2008) in five Tehsils of Parbhani district (Maharashtra) indicated the presence of cocoons of parasitoids, *Promuscidea unfasciatiiventris* Girault parasitizing *P. solenopsis* on cotton and *P. hystrophorus* in four out of the five Tehsils. *P. unfasciatiiventris* parasitoid is a solitary endoparasitoid causing mealybugs to swell and change their colour to light brown. The developing larva at the later stage turns the mealybug into a legless, brown, barrel-shaped mummy with dark brown colour.

Hayat (2009) reported that female of *A. bambawalei* was 1.56 to 2.22 mm in length with body shiny black; head large thimble-like, antenna with radicle black; scape testaceous yellow,

with a brownish patch in middle, while male was 1.04 to 1.45 mm in length and smaller than female.

Pala Ram *et al.* (2009) studied the field parasitization and biology of *A. bambawalei* and observed that nymphal endoparasitoid was very active against mealybug *Phenacoccus solenopsis* and showed 37.6% and 47.2% parasitization on cotton and other host plants. The parasitoid took 12 to 14 days to complete development and caused transformation of parasitized mealybugs into reddish brown mummies and parasitized 38 to 163 mealybugs during life of 11 to 35 days. Also parasitoid had an excellent searching ability.

Saini *et al.* (2009) observed a nymphal parasitoid, *Aenasius* spp. during sampling and rearing of mealybug on cotton which has been recently named as *Aenasius bambawalei* Hayat (Encyrtidae : Hymenoptera). The parasitoid caused 5 to 90 per cent parasitization of this pest in different areas. It also parasitized mealybugs present on other host plants, indicating its great potential for exploitation in biological control.

Bodlah *et al.* (2010) collected the field mummies and brought to the laboratory, reared in four kg capacity transparent plastic jars under controlled conditions at $25\pm 2^{\circ}\text{C}$ temperature, $50 \pm 10\%$ RH and 14 hr photophase for the emergence of parasitoids. Adult parasitoids emerged within 4 to 6 days from mummies.

Solangi and Mahmood (2010) studied biology of *A. bambawalei* under laboratory in Pakistan and stated females of parasitoid lived 10 to 37 days and parasitized 32 to 170 mealybugs. Development of mealybug from day of parasitization to emergence of adults from mummies was completed in 11 to 15 days, while sex ratio in the progeny was 1:2 and parasitoid was

host specific as of the entire mealybugs tested in laboratory it completed development in *P. solenopsis* only.

Fand *et al.* (2011) conducted laboratory experiment for comparing the parasitoid preference for three developmental stages of *P. solenopsis* and its effect on parasitism, development, progeny fitness and sex ratio of *A. bambawalei*. The studies revealed third instar mealybug as the most preferred stage for the development of parasitoid.

According to Vijaya *et al.* (2011) described biological characteristics of *A. bambawalei* under laboratory conditions on *Phenacoccus solenopsis* maintained on potato sprouts and stated it was nymphal endoparasitoid, mean development period of male 12.08 days and female parasitoid 14.08 days, period between oviposition and mummy formation was 5.80 days for both sexes, while pupal period 5.95 days for male and 7.04 days for female. Oviposition period of female was 24.33 days and post-oviposition periods 3.33 days. Total fecundity in terms of parasitized hosts was 100.86. Males were short lived (15.86 days) as compared to females (24.90 days).

Zain-ul-Abdin *et al.* (2012) conducted experiment on *A. bambawalei in vitro* at controlled conditions ($28^{\circ}\text{C} \pm 1$, 70 ± 5 % (RH) and 18 h (L) /6 h (D). The finding showed that after 2 to 4 days of parasitization host swells, ceases its movement and turns into hard leathery structure called “Mummy” after 8 days of parasitization. The period required to complete its development from first day of parasitization till emergence of adults from the mummies was 12 to 17 days. Only single parasitoid adult was emerged from each mummy. Female lived for 15 to 32 days under laboratory conditions, whereas male died within one week. Female of the parasitoid parasitized 165

mealybugs in its entire life and sex ratio of male and female was recorded as 1:2. Further, it is reported that 3rd instar host nymphal stage was the most preferred and suitable stage for parasitization by *A. bambawalei* as compared to other two host stages (1st and 2nd).

Sangale *et al.* (2013) studied life-cycle of *A. bambawalei* in laboratory revealed that egg and larval stages of parasitoid not visible being an internal feeder, but swelling and poor movement of the parasitized mealybug after 2 to 3 days of the parasitization. Parasitized mealybug transformed into dark brown mummies within 4 to 7 days. Pupal period were ranged from 5 to 7 days with length and width varied from 3.43 to 3.53 and 1.74 to 1.94 mm in pupa, 0.79 to 1.27 and 0.30 to 0.51 mm in adult male, 1.40 to 1.79 and 0.71 to 0.89 in adult female, respectively. Longevity of male adults varied from 4 to 8 days while in female it was 9 to 17 days.

2.3 Mass production techniques of *P. solenopsis*

Goldasteh *et al.* (2009) studied development, life history, reproduction and population growth parameters of *Planococcus citri* on colus (*Solenostemon scutellarioides* (L.) at various temperatures ranging from 10 to 37 °C, 70±10% RH and photoperiod length of 16:8 h (L:D). Females and males successfully developed into adults at 15 to 32 °C and 18 to 32 °C, respectively. All first instars died at 10, 12 and 37 °C. Lower temperatures (10, 12 and 15 °C) caused higher egg mortality than higher temperatures (32, 35 and 37 °C). The sex ratio was female-biased between 15 to 30 °C, but there were a slightly higher number of males at 32 °C. The highest adult longevities of females and males were obtained at 18 to 25 °C, respectively. The highest fecundity was observed at 23 °C.

According to Fand *et al.* (2010) continuous rearing of *P. solenopsis* on sprouted potato tubers for six generations in the laboratory at 27 ± 2 °C and $65 \pm 5\%$ RH was possible. A group of 100 newly emerged (0 to 24 h old) crawlers of *P. solenopsis* was kept separately in small plastic jars (10×7.5 cm) having sprouted potato tubers and were observed daily for subsequent development and survival upto their last nymphal stage. The development time and mortality of crawlers during each instar were recorded.

P. solenopsis can easily be reared and multiplied under laboratory conditions at the temperature range between 15 to 30 °C and relative humidity 50 to 90 per cent (Anonymous, 2011). Fine field soil mixed with vermicompost (1:1) was filled (about 1-1.5 inch) in a plastic container (12 inch dia.), 6-10 sprouted potatoes were placed (depending upon size of potato) on the soil. The soil was moistened; culture of *P. solenopsis* was released and allowed to settle. Mealybug population was ready in a month from release of culture.

The laboratory experiments to study the developmental rates of *P. solenopsis* at different constant temperatures *viz.* 25, 27, 30 and 32 °C revealed that mean fecundity was maximum i.e. 434.4 ± 155.21 (range 281-723) at 25 °C and found to be decreasing with increase in temperature (Anonymous, 2011). The results also revealed that number of eggs observed per female also showed increasing trend. However the incubation period varied and did not demonstrate any trend. Nymphal developmental period was maximum at 25 °C in all instars (total duration in the range of 22 to 44 days) and found to be less in subsequent temperatures except 32 °C where nymphal period increased by few days. The nymphal period

increased with decrease in temperature. Adult female longevity was maximum at both 25 and 27°C temperatures.

Satpute *et al.* (2011) studied the biology of mealybug *Phenacoccus solenopsis* (Tinsley) on different hosts under laboratory condition and the total developmental period of female nymphs was 22.5, 26 and 23.5 days on cotton, *Hibiscus* and sprouted potato, respectively. The longevity of an adult female varied from 10 to 13 days on cotton, 11 to 14 days on *Hibiscus* and 11 to 14 days on sprouted potatoes. The fecundity was more when the mealybugs were fed on *Hibiscus* than the other two hosts.

Muhammad *et al.* (2012) observed phenological response of cotton mealybug (*Phenacoccus solenopsis* Tinsley) on three prominent host plants i.e., cotton, China rose and okra under laboratory. Studies revealed that the development of all female nymphal instars was more rapid on cotton followed by China rose and okra, whereas the development of male nymphal instars was fastest on China rose followed by cotton and okra. The pre-oviposition period was 9.58 on cotton, 8.38 days on China rose and 8.75 days on okra. Oviposition period was 12.47 days on Chinrose followed by 8.99 days on cotton and 6.77 days on okra. Maximum number of 265 eggs was laid on cotton followed by 212.6 eggs and 160.2 eggs on China rose and okra, respectively.

Prasad *et al.* (2012) recorded the effect of temperature on life cycle of the solenopsis mealybug, *P. solenopsis* on cotton was assessed under laboratory conditions at ten constant temperatures (18 to 40 °C). The development duration of female and male nymphal instars linearly decreased with the increase in temperature from 18 to 32 °C. Cumulative developmental time

of female ranged from 43.9 d (18 °C) to 15.0 d (32 °C) the solenopsis mealybug exhibited obligate sexual ovoviviparous reproduction and the oviposition period of 10.2 to 11.5 d at 25 °C was nearly half the duration than at 20 °C and the highest fecundity 245 crawlers was observed at 30 °C. The longevity of mated females was significantly prolonged at 20 °C (46 d) compared to 30 °C (21.4 d). Proportion of females was highest (97.5 %) at 25 °C.

2.4 Mass multiplication of *A. bambawalei*

Fand *et al.* (2011) conducted experiment on *A. bambawalei* at 27.00±2 °C, temperature, 65±5 per cent relative humidity and 16 h L:8 h D photoperiod in the biological control laboratory IARI, New Delhi during 2008-2009. Parasitized mealybugs (mummies) were collected from field and reared. The parasitoid was reared for eight generations in the laboratory.

Huang *et al.* (2012) evaluated control effects of *A. bambawalei* on 3rd instar nymphs and female adults of *P. solenopsis*, the parasitic functional response and density effects of *A. bambawalei* to *P. solenopsis* were determined under the laboratory conditions of 25±1 °C, RH 70 per cent and 14 h L:10 h D. The numbers of parasitized hosts were decreased with the increasing densities of *A. bambawalei*. The parasitizing efficiency was 21.13 for 3rd instar nymph and 6.25 for female adults.

Zain-ul-Abdin *et al.* (2012) conducted experiment on the endophagous Encyrtid parasitic wasps *Aenasius bambawalei* Hayat which were reared on the colonies of its host *Phenacoccus solenopsis* Tinsley maintained on pumpkin. Parasitized mealybug or mummies were collected in plastic jars directly from the fields of cotton and vegetables (e.g. tomato, egg plant, okra, pumpkin etc.). Mealybug and parasitoid cultures were

maintained in two separate glass jars, both at $28^{\circ}\text{C} \pm 1$, 70 ± 5 per cent relative humidity (RH) and 18 h (L)/6 h (D) photoperiod. Naive/virgin parasitoid adults were obtained from mummies of mealybug kept singly in glass vials, plugged with cotton wool in the laboratory. Effective parasitization was obvious when the parasitized mealybug shedded its wax, swelled and hardened into a leathery, brown colored structure called “mummy”. Complete development of parasitoid larvae depended upon the temperature and other environmental factors. The adults of *A. bambawalei* were separated by sexes: morphologically the females are easily distinguished from the males by their pointed/conical abdomen (ovipositor).

2.5 Toxicity of different insecticides against *A. bambawalei*

Evans (1966) found that dicrotophos virtually did not leave residual toxic to the adults of *Anagyrus* spp.

Furness (1977) noted the mortality of *Anagyrus fusciventris* (Grit.) with maldison, methidathion, methomyl and aminocarb. The LD_{50} values ranged from 0.003 to 0.02 for *A. fusciventris*. Parasitoids were emerged from the insecticide treated mealybug mummies.

A. pseudococci adults were exposed to leaf surface treated with pesticides namely methidathion, carbophenathion, azinphosmethyl, chlorobenzilate, ethion and oil. The residual toxicity of azinphosmethyl and oil combinations gave the highest natural enemy mortality over 35 days post treatment, while a chlorobenzilate-oil combination resulted in the lowest mortality (Meyerdirk *et al.*, 1979).

Mani (1992) recorded that mealybug parasitoids like *Aenasius advena* Comp. and *Blepyrus insularis* (Cam.) were

exposed to the guava leaves treated with different insecticides i.e. diazinon (0.05%) was found to be non-toxic to *A. advena* and least toxic to *B. insularis*. The other chemicals such as endosulfan (0.07%), phosalone (0.07%) and dichlorvos (0.20%) showed lesser toxic residual effect while chlorpyrifos (0.05%), carbaryl (0.10%) and fenthion (0.10%) recorded significantly higher residual effect to both the parasitoids.

Walton and Pringle (1999) determined the effect of regularly used table grape insecticides and fungicides on 1 day-old adults of the parasitoid *Coccidoxenoides peregrinus* (Timberlake) of vine mealybug, *Planococcus ficus* (Signoret), in the laboratory. The insecticides chlorpyrifos, endosulfan and cypermethrin were highly toxic to the parasitoid, while the fungicides penconazole and mancozeb were not. Results suggested that the insecticides may be detrimental to a biological control system using *C. peregrines*.

Neem oil and NSKE was caused 100 per cent mortality only after 24h in both the sexes of the parasitoid (Lowery and Isman, 1995) and Tang *et al.* (2002) reported that neem formulations have minimum toxicity to non target organisms and negative effect on parasitoid survival and emergence.

According to Raymond and Dickinson (2006) the low toxicity of IGRs i.e. buprofezin 25 SC, who reported that buprofezin, pyriproxyfen, and flonicamid were not harmful to *Leptomastix dactylopii* when applied at the label rate. Both buprofezin and flonicamid were not toxic to *L. dactylopii* with 100 per cent adult survival after 72 h. Dinotefuran was extremely detrimental to the adult parasitoid at the label rate with 100 percent mortality after 24 h.

Nalini and Manickavasagam (2011) studied toxicity of selected insecticides against mealybug parasitoid *Aenasius bambawalei* Hayat and *Aenasius advena* Compere by using dry film method at 1,3,6,12,18 and 24 days after treatment. Results showed that endosulfan, monocrotophos, profenophos and dimethoate caused 100 per cent mortality within 1h in both parasitoids. In case of imidacloprid was comparatively safer and caused 100 per cent mortality of both the sexes of parasitoid after 3h. However nimbecidine caused 100 per cent mortality only after 24h.

2.6 Activity of *P. solenopsis* on different host plants

Because of its polyphagous nature *P. solenopsis* has been recorded from a large number of host plants.

P. solenopsis is a polyphagous pest feeding and reproducing on wide range of plants. Literature survey on pest status of *P. solenopsis* indicated severe economic damage to wide range of vegetables, horticultural and field crops. *P. solenopsis* infestation on cotton and 29 other host plant species of 13 families was reported in the U.S. (Fuchs *et al.*, 1991).

Mani (1986) stated that the pink *Hibiscus* mealybug; *M. hirsutus* was reported as a pest of many plants, trees, and shrubs. It infests *Hibiscus*, citrus, coffee, sugarcane, annonas, plums, guava, mango, okra, sorrel, teak, pigeon pea, peanut, grape vines, maize, asparagus, chrysanthemum, beans, cotton, soybean, cocoa, and many other plants.

Tanwar *et al.* (2007) found that mealybugs are polyphagous, feeding on variety of plants belonging to Malvaceae, Solanaceae and Leguminaceae. The host range of mealybugs includes grape, fig, date palm, apple, avocado, banana, citrus, okra, tomato, brinjal, cotton and few

ornamentals. *Hibiscus rosa sinensis* is a typical host which is frequently attacked by *Maconellicoccus hirsutus*.

Dhawan *et al.* (2007) revealed that carryover and spread of mealybugs were mainly through the weeds in cotton fields. Polyphagous nature of cotton mealybug was the reason for migration to number of plants after the uprooting of cotton stalks. Besides, this pest can also survive on a number of tree plantations during the off-season.

Parthenium hysterophorus L. was the most preferred host and as good as breeding sites for the pest. Mealybugs survived on this host and then migrated to cotton (Acharya *et al.*, 2008).

Rathod *et al.* (2008) conducted the survey and found an unusual severe infestation of mealybug, *M. hirsutus* on sunflower, *Helianthus annuus* L. which is an important oilseed crop grown in *Kharif*, *rabi* and summer seasons in Western Vidarbha, Maharashtra.

Aheer *et al.* (2009) reported that twenty two host plants were studied for the prevalence of cotton mealybug, *Phenacoccus solenopsis* from December 2006 to November 2007 in the area around Faisalabad city. Maximum prevalence was observed on China rose (*Hibiscus chinensis*) followed by okra (*Abelmoschus esculentus*) with maximum of 8.11 and 5.41 per cent incidence, respectively. Mealybug remained throughout study period on China rose; whereas Nagarare *et al.* (2009) reported that *P. solenopsis* was found on cotton and other crops of 14 families in India.

Arif *et al.* (2009) found that *P. solenopsis* attained the status of a serious pest on a wide range of host plants. It was recorded from 154 plant species including field crops, vegetables, ornamental, weeds, bushes and trees. Most of

those belong to the families Malvaceae, Solanaceae, Asteraceae, Euphorbiaceae, Amaranthaceae and Cucurbitaceae.

Deshmukh *et al.* (2009) made survey for host range under the rainfed cotton production system which revealed a total record of 91 host plants spread across 24 families. *P. solenopsis* was found multiplying on 30 host plants during the cotton growing season and 61 plants exclusively during off-season. Ten and 27 host plants had the highest severity of Grade 4 during cotton and off seasons, respectively. Plant species from three families *viz.*, Compositae, Leguminaceae and Malvaceae constituted 50 per cent of the host plants of *P. solenopsis*. Most preferred host plant families of mealybug were in the order of Compositae (10)>Leguminaceae and Malvaceae (8 each)>Amaranthaceae, Euphorbiaceae and Solanaceae (4 each)>Graminae (3)>Convolvulaceae and Labiatae (2 each). Off season hosts were higher than the growing season indicating the strong carry over between successive cotton seasons.

Saini *et al.* (2009) found that cotton mealybug survived on more than 28 species of plants, including okra, egg plant, sesame, guava and some ornamental plants. The most preferred hosts were *Gossypium* spp., *Parthenium hysterophorus* L., *Trianthema portulacastrum* L., *Xanthium strumarium* L., *Tribulus terrestris* L., *Abutilon indicum* L., *Conyza canadensis* L., *Achyranthes aspara* L., *Chenopodium* spp., *Hibiscus rosasinensis* L., *Withtmia somnifem* L., etc. From July to December, the pest survived on cotton, *T. partulacastrum*, *P. hysterophorus*, *T. lerrestris*, *A. indicum*, *C. canadensis*, *Physalis minima*, *A. aspara*, *Chenopodium* spp., *Helianthus annus* L., *Azadirachta indica* A. Juss, *W. somnifera*, *Datura metel*, *Peristrophe peniculata* and several other unidentified host plants. In January

- February, it survived in winter season on stacks of cotton, *C. canadensis*, *A. aspara*, *P. hysterothorus* and *A. indicum*. During March-April, it developed on *W. sominifera*, sprouts from cotton stubbles and *H. rosasinensis*. During May-June, it thrived on early sown cotton, *P. hysterothorus*, *H. rosasinensis*, etc. During winter the pest population declined drastically but it could survive in low numbers on plants growing under trees and shrubs where adverse effect of low temperature on its host plants was less pronounced.

Suresh *et al.* (2010) revealed that earlier *P. solenopsis* was predominant in many places of Tamil Nadu and was slowly replaced by *P. marginatus* especially in Coimbatore, Erode and Tiruppur districts. The level of incidence varied from nil to 60 per cent on many crops. They also recorded sunflower, vegetables (brinjal, tomato, bhendi, and cucurbits), pulses and parthenium as alternative hosts of *P. solenopsis*.

2.7 Evaluation of different insecticides for the management of *P. solenopsis*

Narasimha Rao *et al.* (1977) inferred that, dichlorvos (0.15%) with combination of fish oil rosin soap (2.5%) gave 80 per cent mortality of mealybugs while dichlorvos (0.15%) alone gave 67 per cent mortality. The effectiveness on the mortality of the mealybug was reported to be the highest for dichlorvos, followed by fenvalerate and monocrotophos at post spraying (Anonymous, 1982).

Beevi *et al.* (1992) tested ten insecticides as sprays in laboratory against eggs of mealybug, *M. hirsutus*. Hatching was least in eggs treated with neem oil (0.3%) followed by monocrotophos (0.04%), methyl demeton (0.04%) and fish oil rosin soap (2.5%) + dichlorvos (0.2%). Hatta and Hara (1992)

reported that spraying with chlorpyrifos (0.03%) totally eliminated pseudococcids on ginger in Hawaii.

Bedford *et al.* (1996) reported that the buprofezin against mealybug (*Planococcus citri*) on celery plants reduced the infestation significantly and the effects on mealybugs were greater with higher rate of buprofezin applied.

Vergheze (1997) studied the effects of 5 and 2.5 per cent neem seed kernel extracts and Azadirachtin (Econeem) 9 ppm on newly hatched and late first instar (4 day old) nymphs of *M. hirsutus* under laboratory. After 24 and 48 h, mortality of early first instar nymph was greatest with 5 per cent NSKE. The mortality of late first instar nymphs after 24 and 48 h was greatest with 9 ppm Azadirachtin.

Irulandi *et al.* (2001) found that spraying of neem formulations alone at 15 ml or 25 ml/lit resulted in a significant reduction of 86.56 to 88.33 per cent of coffee mealybug (*Planococcus citri*) population as against 83.55% at recommended dose of quinalphos 20 AF. Combination sprays of azadirachtin 10 ml + quinalphos 0.75 ml/lit recorded maximum control of coffee mealybugs (86.82 per cent).

Balikai (2002) noted that buprofezin 25 SC @ 1000 ml ha⁻¹ recorded maximum control of 80.4 per cent of mealybug, *M. hirsutus* population on grape when sprayed along with fish oil rosin soap (Meenark) @ 3125 g ha⁻¹.

Similarly, Balikai (2005) recommended buprofezin 25 SC @ 1125 ml ha⁻¹ along with fish oil rosin soap (Meenark) at 3125 g ha⁻¹ for the management of mealybug, *Maconellicoccus hirsutus* (Green) on grape vines.

According to Muthukrishan *et al.* (2005) buprofezin as foliar spray at 1125 and 1500 ml ha⁻¹ reduced the nymphal

and adult population and bunch infestation of *M. hirsutus* and increased the fruit yield as compared to untreated check and recommended insecticides. As the efficacy of both the doses was statistically on par, the lower dose of 1125 ml ha⁻¹ was sufficient to effectively mitigate the mealybug colonies. There were no phytotoxic symptoms observed on any part of the treated plants due to any of the insecticides

Gonzales and Volosky (2006) reported that pre-bloom applications of buprofezin produced the longest sustainable mortality rates of mealybugs, *Pseudococcus* spp. in pome fruits, table and wine grapes.

Vaughn *et al.* (2006) revealed that mating disruption was most effective when the mealybug density was low, suggesting that a combination of buprofezin application and mating disruption may be necessary for best results, at least initially.

Zaka *et al.* (2006) worked on the relative efficacy of different pesticides against cotton mealybug in Pakistan. They concluded that methomyl, triazophos and methamidophos were the most effective pesticides against cotton mealybug, followed by imidacloprid.

According to Dhawan *et al.* (2007) management of mealybug involves several aspects *viz.*, control of care taking ants, uprooting and destroying the alternate host plants of mealybug growing on field bunds, water channels and wastelands in the area during the off-season of cotton etc. The cultural operations should be followed at monthly interval up to end of May. The recommended insecticides were carbamates like carbaryl 50 WP and thiodicarb 75 WP and organophosphates

like profenophos 50 EC, quinalphos 25 EC, acephate 75 SP, and chlorpyriphos 20 EC.

Tanwar *et al.* (2007) gave a report on recent mealybug infestations on various economic crops in India, and reported nine major mealybug species (eight Pseudococcidae and one Monophlebidae). A number of pesticides: lamdacyhalothrin (Boxer, 2.5 EC), bifenthrin (Talstar, 10 EC), profenophos (Craker, 50 EC), imidacloprid (Crown, 200 SL), abamectin (Alarm, 1.8 EC), emamectin benzoate (Proclaim, 19 EC), chlorpyriphos (Lorsban, 40 EC), methidathion (Supracide, 40 EC), carbosulphan (Advantage, 20 EC), acetamiprid (Rani, 20 EC) were tested in a laboratory bioassay and then in the field. After 72 hours profenophos was most effective, followed by methidathion and bifenthrin (with mortality rates of 68.34, 65.83 and 48.23 %, respectively).

Similar results were reported by Saeed *et al.* (2007), who tested insecticides of different groups against cotton mealybug in the laboratory as well as in the field in Pakistan. In the laboratory, using the leaf dip method, bifenthrin, profenophos and chlorpyriphos proved to be the best insecticides for mealybug control, based on the LC₅₀. In field conditions the recommended application rates of methomyl, profenophos and chlorpyriphos provided the best control; lethal time studies proved their efficiency for timely control of this sporadic pest.

Dhawan *et al.* (2008) reported that the order of toxicity of insecticides was spirotetramat > clothianidin > profenophos > thiodicarb > quinalphos > buprofezin > acephate with their relative toxicity values being 5.05, 2.93, 1.00, 0.84, 0.82, 0.29, 0.25 $\mu\text{g mL}^{-1}$ for one day old nymph/crawlers and 5.29, 2.41, 1.00, 0.96, 0.73, 0.35, 0.19 $\mu\text{g mL}^{-1}$ for the adult

female, respectively. Profenophos and thiodicarb proved to be the best insecticides for mealybug control. Acephate was found to be least toxic against both nymph and adult mealybug.

Dhawan *et al.* (2008) stated that emamectin benzoate was the most effective against cotton mealybug in a bioassay test, followed by chlorantraniliprole, pyridalyl, novaluron, quinalphos, thiodicarb, flubendiamide, acephate and chlorpyrifos; endosulfan being the least effective.

Saini and Ram (2008) found that profenophos, thiodicarb, quinalphos, and acephate gave more than 90 per cent kill of the pest using the recommended doses and 200 litres of water per acre as spray material.

Agarwal *et al.* (2009) evaluated nine treatments of spirotetramat and imidacloprid in mixtures and alone at different doses including two checks, thiodicarb (Larvin 75 WP) and profenophos (Curacron 50 EC) and compared their effectiveness against mealybug infestation on cotton. Three days after second spray, profenophos 50 EC (check) recorded 93.73 per cent mortality over control and was at par with spirotetramat 12% + imidacloprid 36% 480 SC @ 36+108 g ai ha⁻¹ (85.09% mortality) and thiodicarb 75 WP @ 750 g ai ha⁻¹ (84.48% mortality).

Out of 12 insecticides tried as curative spray at 2, 7 and 14 days, acephate 70 SP, followed by profenophos 50 EC and dichlorvos 76 EC were effective in the management of mealybug. The yield of seed cotton was significantly highest in acephate 70 SP (22.2 q ha⁻¹) and profenophos 50 EC (22.2 q ha⁻¹) which were at par with each other (Bhosle *et al.* 2009).

Further Dhawan *et al.* (2009) made studies on persistence and residual toxicity of profenophos, thiodicarb,

buprofezin, quinalphos, chlorantraniliprole, spirotetramat, acephate, carbaryl and chlorpyrifos at recommended concentrations on field cotton against first instar and adult female of mealybug *Phenacoccus solenopsis*. Based on the index of persistence toxicity, the order of effectiveness for the crawlers of *P. solenopsis* was profenophos (637.1)>thiodicarb (587.9)>buprofezin (492.3) >quinalphos (407.9) chlorantraniliprole (380.0) > spirotetramat (371.6) > acephate (345.7) > carbaryl (314.6) > chlorpyrifos (273.4). Similarly, for the adult female this order of effectiveness was profenophos (572.9) > buprofezin (483.1) > thiodicarb (430.0)>) > quinalphos (379.9) chlorantraniliprole (371.6)> spirotetramat (361.3) > acephate (296.7) > carbaryl (260.0) >chlorpyrifos (252.3).

Deshmukh *et al.* (2009) reported the occurrence of *P. solenopsis* on large number of weed hosts over agriculturally important crop plants. Cultural management practices such as field sanitation, weed removal and disposal during crop and off seasons play a significant role in preventing spread of *P. solenopsis*.

Kharbade *et al.* (2009) recorded that *Metarhizium anisopliae* @ 2000 g ha⁻¹ was the most effective by recording minimum of 87.46 mealybugs/5 cm shoot tip length/plant resulting in noticeable reduction of mealybugs over untreated control. This treatment was statistically on par with Neem oil 2000 ml ha⁻¹ and Dashparni @ 10% in which average of 108.73 and 110. 33 mealybugs/ 5 cm shoot tip length/ plants were noticed, respectively. The higher seed cotton yield of 1521 kg ha⁻¹ was obtained in treatment with *M. anisopliae* @ 2000 g ha⁻¹ as against 913 kg ha⁻¹ in untreated control.

Pinjarkar *et al.* (2009) recorded parasitoids belonging to the families Encyrtidae and Aphelinidae of Hymenoptera. These parasitoids regulated the population of *P. solenopsis* and *M. hirsutus* effectively under field conditions. They also opined that strategies of mealybug management should emphasize on the priority for natural control coupled with cultural practices before the curative insecticides spray in tackling mealybugs in cotton fields.

Patel *et al.* (2010) reported that more than 95 per cent reduction in mealybug population over control was observed after 3 DAS in buprofezin in all the three doses (250, 312.5 and 625 g a.i. ha⁻¹). The efficacy of buprofezin against early and later instar nymphs of *P. solenopsis* under laboratory condition was also found to be dose dependent and it was more toxic to early instars than later instar nymphs. At lower 2 doses (250 g a.i. ha⁻¹ and 312.5 g a.i. ha⁻¹), its effectiveness was comparable to chlorpyrifos 400 g a.i. ha⁻¹ and carbaryl 1000 g a.i. ha⁻¹. An early chemical control effort against *P. solenopsis* in the USA proved unsatisfactory (Fuchs *et al.*, 1991).

Suresh *et al.* (2010) evaluated efficacy of different insecticides/entomopathogens against *P. solenopsis*. The insecticides, profenophos and methyl parathion were found to be quite effective and caused cent per cent mortality one day after treatment while imidacloprid, fish oil rosin soap and dimethoate caused cent per cent mortality after two days of the treatment imposition. All the tested insecticides were found to be quite effective upto 10 days of application. *Beauveria* was found to be moderately effective and caused 77 per cent mortality after 10 days of treatment.

3. MATERIAL AND METHODS

The laboratory investigations were carried out under controlled conditions at 27 ± 2 °C temperature and $65 \pm 5\%$ RH in the Biological Control Laboratory and field study was conducted at field of Department of Agricultural Entomology, MPKV, Rahuri during *Kharif*, 2008 and *Kharif*, 2009. The details of the rearing equipments and chemicals used, the methodology adopted for recording observations on various aspects under study and statistical analysis used for interpretation of the results are discussed briefly in this chapter.

3.1 Material

3.1.1 Glasswares

- i. Plastic and glass jars (15 x 15 x 15 cm and 20 x 15 cm) for rearing of *Phenacoccus solenopsis* Tinsley and its parasitoid, *Aenasius bambawalei* Hayat.
- ii. Glass vials of 15 x 2.5 cm size for individual rearing of parasitoids for studying their parasitization potential and biology.
- iii. Glass petriplates of 10 cm diameter for parasitization studies.
- iv. Plastic trays (30 x 10 cm and 15 x 7.5 cm size) for keeping the vials and the petriplates.

3.1.2 Equipments

- i. Binocular microscope with an incident light for observing different growth stages of the insects under study.
- ii. BOD incubator for maintaining required temperature (27 ± 2 °C) and relative humidity ($65 \pm 5\%$) conditions for optimum growth of the insects under study.

3.1.3 Experimental material

- i. Sprouted potato as a substrate for growing mealybug culture in the laboratory.
- ii. Nucleus culture of mealybug, *P. solenopsis* reared on sprouted potato.
- iii. Nucleus culture of parasitoid, *A. bambawalei* maintained on the mealybug *P. solenopsis*.

3.1.4 Chemicals

- i. Formalin solution (1%) for disinfection of the potato tubers, rearing containers and glasswares in order to avoid any unwanted contamination or spoilage of tubers due to fungal / bacterial infections.
- ii. Ethyl alcohol (70%) for disinfection and preservation of various stages of mealybug.

3.1.5 Miscellaneous

- i. Black and white muslin cloth and rubber bands to cover the rearing jars.
- ii. Cotton plugs, tissue paper, blotting paper, etc
- iii. Needles, forceps, camel hair brush for handling of the nymphs of mealybugs.
- iv. Honey solution 20 per cent as a food for the adults of a parasitoid.
- v. Wooden cages (60 x 30 x 30 cm) for rearing of mealybugs and parasitoids.

3.2 Methodology

3.2.1 Programme of research work

The programme of research work consisted of:

1. Study biology of cotton mealybug *Phenacoccus solenopsis* (Tinsley) and its parasitoid.

2. Mass production of cotton mealybug as host for parasitoid.
3. Mass multiplication of parasitoid of cotton mealybug.
4. Evaluation of different insecticides and biopesticides for management of cotton mealybug *P. solenopsis*.

3.2.2 Maintenance of *P. solenopsis* culture on sprouted potatoes

Initial culture of *P. solenopsis* was collected from mealybug infested twigs of cotton plants from the field of Cotton Improvement Project, MPKV, Rahuri and reared on sprouted potato tubers in insect rearing room in the Department of Entomology, Post Graduate Institute, MPKV, Rahuri by the method suggested by Fisher (1963) and Gautam (2008b) (Plate 1). Fresh potato were thoroughly washed with water and kept aside till the water evaporated from the surface of tubers. The potatoes were wrapped in moist gunny bag for sprouting at room temperature of 24-25 °C for 8 days. Plastic trays (30 × 20 × 5 cm) were filled with sandy silt loam soil and then 7 to 8 sprouted tubers were placed at about 2 cm apart in each tray and covered with slightly moist soil. These trays were kept in rearing room and watered gently. Temperature in the rearing room was maintained between 21 to 25 °C (Mani and Krishnamurthy, 1990). Ovisacs of the mealybugs obtained from cotton fields were placed over the sprouts. Newly emerged crawlers or 2-3 adult females were released on the potato sprouts with the help of camel hair brush. The jars were covered with clean black muslin cloth and tied with the rubber band. The jars were kept at 27 ± 2 °C and 65 ± 5% RH. The mealybug culture was developed fully after 10 to 12 days. Different stages of *P. solenopsis* required for

various experiments reported in this study were drawn from the mass rearing culture.

3.2.3 Maintenance of *A. bambawalei* culture

Field collected mealybug parasitoid was, got identified as *Aenasius bambawalei* Hayat from Division of Entomology, IARI, New Delhi. The initial culture (cocoon) of *A. bambawalei* was collected from parasitized mealybugs, *P. solenopsis* from the cotton fields of Cotton Improvement Project, MPKV, Rahuri and kept in plastic jars in the wooden cages (60 × 30 × 30 cm) (Plate 2). The parasitoid adults emerged were released on sprouted potatoes infested with *P. solenopsis* in wooden cages for laboratory rearing of the parasitoid *A. bambawalei*. The endoparasitoid females parasitized full grown nymphs and adults of mealybugs kept in cage. The parasitized mealybugs were recognized due to their dark brown colour and barrel shape hard case, brittle in consistency. The parasitoid adults emerged out within a week. Honey streaks (20 %) were provided on inner wall of plastic jars as a food to the adults. Thus parasitoid *A. bambawalei* culture was reared in the laboratory at $25 \pm 2^{\circ}\text{C}$ and $65 \pm 5\%$ RH and was established for various experiments reported in this study.

3.3 Biology and mass multiplication of *P. solenopsis*

The experiment on biology of cotton mealybug *Phenacoccus solenopsis* (Tinsley) was conducted under laboratory conditions at Department of Agricultural Entomology, Post Graduate Institute, MPKV, Rahuri during *Kharif*, 2008.

3.3.1 Biology of mealybug, *P. solenopsis*

The coarsely sieved soil mixed with vermicompost (1:1) was filled (about 1-2 inches) in a plastic tray (12 inch dia.) 10-12

sprouted potatoes were placed on the soil and the soil was moistened. Newly emerged crawlers and 2-3 gravid females of *P. solenopsis* were released on the potato sprouts with the help of camel hair brush and allowed to settle and trays were kept in wooden cages (60 × 30 × 30 cm). The jars were kept at $25 \pm 2^{\circ}\text{C}$ and $65 \pm 5\%$ RH in separate cages. Simultaneously, cotton and *Hibiscus* plants were grown in earthen pots in the glass house of the Department of Entomology. After one month, females of mealybug were released on the plants. To study biology of cotton mealybug freshly emerged 25 nymphs were kept on sprouted potatoes placed on moistened sand in round plastic transparent jars at $25 \pm 2^{\circ}\text{C}$ and $65 \pm 5\%$ RH. The observations were recorded twice a day to examine the mealybug stages, durations, size, colour and reproduction potential.

3.3.1.1 Nymphal instars

Newly hatched twenty five 1st instar nymphs were transferred on well washed and blotted separate leaves and sprouted potatoes in a petridish (Plate 3). The insect was observed daily for molting under dissecting microscope at 10 x magnification. The exuviae seen in the petridish indicated the change in instar. The linear measurement on body width and body length of each instar was recorded with ocular and stage micrometer. The number of days from egg hatching till full growth of nymphs was recorded to workout nymphal period.

3.3.1.2 Adult morphometrics

The observations on morphological characters and dimensions of 25 male and female individuals using ocular and stage micrometer were recorded.

3.3.1.3 Pre-oviposition period

The duration between moulting of third instar to deposition of first egg sac by individual female mealybug was recorded to workout pre-oviposition period.

3.3.1.4 Oviposition period

The duration between depositions of first egg sac to last egg sac by individual female mealybug was recorded to workout oviposition period.

3.3.1.5 Post-oviposition period

The duration between end of egg production and mortality of female was recorded to workout post-oviposition period.

3.3.1.6 Fecundity

The average total number of eggs/crawlers laid by each female during its life span was counted.

3.3.1.7 Adult longevity

The average longevity of 25 males and females was the duration between adult emergence to mortality, whereas the total life was calculated as the duration from the egg laying to mortality. The average longevity and total life of both the males and females was calculated.

3.3.1.8 Sex ratio

Infested twigs (top 3 cm portion of a tender, growing cotton shoot) were collected with hundred nymphal mealybugs from the field and brought to the laboratory and kept in a 5.5 cm diameter transparent plastic petridish containing fresh leaf pieces of host plant. After 1 to 7 days the mealybugs moulted to the third instar in the case of females and to a prepupa in the case of males. The number of each sex was counted for calculation of the sex ratio.

3.3.2 Mass multiplication of mealybug, *P. solenopsis*

For mass multiplication of *P. solenopsis* in the laboratory, potato tubers were kept in BOD incubator at 27 ± 2 °C for sprouting. When the sprouts reached about 1 to 2 cm in height, the potatoes were taken out from the incubator and placed in glass jars (20 × 15 cm) covered with muslin cloth. Mealybugs were collected from the infested plants in the field of Cotton Improvement Project, MPKV, Rahuri and brought to the laboratory. The 2nd instar crawlers of mealybugs present on such twigs were gently removed with the help of soft moist camel hair brush and released on to the potato sprouts in the glass jars. These 2nd instar crawlers were kept in the laboratory at room temperature to facilitate multiplication. Twenty five such jars and plastic trays having 10-12 sprouted potatoes each with 40-50 mealybugs released on them were maintained in laboratory for obtaining test insect for further experiments.

The experiments were conducted to study bionomics of *P. solenopsis* on three different prominent host plants viz., cotton (*Gossypium* spp.), potato sprouts (*Solanum tuberosum* L) and China rose (*Hibiscus* spp.) (Plate 4). The newly emerged 25 first instar nymphs of cotton mealybug were placed on fresh leaves in petridishes. The developmental stages of newly emerged nymphs were observed till their mortality. The females were observed daily for egg deposition. The developmental durations of each nymphal instar for male and female were calculated for individual insect on all the test host plants. The parameters recorded were number of individuals reaching to adult stage, total nymphal period, male pupal period, pre-oviposition, oviposition, post-oviposition period, fecundity, male- female longevity and sex ratio. The leaves of test host plants were

replaced every two days with fresh leaves. The data was recorded daily.

An another experiment was conducted on development and growth parameters of *P. solenopsis* on sprouted potatoes at different constant temperature conditions viz. 25, 27, 30 and 32 °C in laboratory. The females from stock culture were placed to lay eggs on sprouted potatoes. After laying of egg ovisacs, all the adult females were removed, while crawlers were kept for observations. Developmental duration of nymphs was determined for each nymphal instar. They were monitored daily until maturity, and presence of exuviae was examined to identify each instar stage. During reproductive period, newly laid eggs were counted and removed daily until all females died. The parameters recorded were total nymphal period, pre-oviposition, oviposition, post-oviposition period, fecundity, male- female longevity and sex ratio.

3.4 Biology and mass multiplication of *A. bambawalei*

3.4.1 Biology of parasitoid, *A. bambawalei*

The experiment on biology and mass multiplication of *A. bambawalei* was conducted under laboratory conditions at 25 ± 2 °C and $65 \pm 5\%$ RH at Department of Agricultural Entomology, Post Graduate Institute, MPKV, Rahuri during *Kharif*, 2009. The parasitized mealybugs (mummified cocoon) (Plate 5 and 6) were collected from the mealybug infested plants of cotton from the field of Cotton Improvement Project, MPKV, Rahuri and kept in plastic jars in the wooden cages (60 × 30 × 30 cm). The adults emerged were released on sprouted potatoes infested with *P. solenopsis* in wooden cages.

The experiment on biology of visual stages of *A. bambawalei* was initiated by collecting mummified pupa of parasitoid *A. bambawalei* from culturing jars (capacity 15 × 15 × 15 cm) and placing them in small glass vials (10 × 2.5 cm) until adult emergence. Freshly emerged adults were held in a glass vial for 48 h to ensure mating and provided 20 per cent honey solution as a food on cotton swab. Twenty five 3rd instar nymphs of mealybugs were transferred from the rearing culture of mealybug into individual petridishes (1 × 9 cm) having cotton leaves and 25 pairs of freshly emerged male and female parasitoids were released in each petridish. Parasitoids were allowed to parasitize the host insects in the petridish for 24 h. The parasitized nymphs were provided with fresh cotton leaves until formation of cocoon.

After few days parasitized swollen mealybugs ceased their movement and turned into kidney bean shape like pupae. Only single adult parasitoid emerged from each mummified pupa. The developmental period of the parasitoid was examined regularly till the emergence of adult parasitoids from mummified pupae and observations were recorded on developmental periods of parasitoid i.e. sex ratio, male and female longevity, and fecundity (parasitized mealybug). Observations on duration of larval period, pupal period and adults were recorded. Different visual stages such as pupae and adults were critically examined under binocular microscope for their colour and shape.

3.4.1.1 Adult morphometrics

The observations on the morphometrics of body width and length of male and female parasitoid were recorded by using ocular and stage micrometer.

3.4.1.2 Larval period

The duration between day of exposure of mealybug to parasitoid and day of mummification was counted as larval period and male and female larval period was computed after adult parasitoid emergence.

3.4.1.3 Pupal period

The duration between day of mummification and day of emergence of adults was counted as pupal period and male and female pupal period was calculated after adult parasitoid emergence.

3.4.1.4 Oviposition period

The duration between parasitization of first mealybug to last mealybug was recorded to workout oviposition period.

3.4.1.5 Post-oviposition period

The period after last mealybug parasitization to mortality of adult was recorded to workout post-oviposition period.

3.4.1.6 Fecundity

Each *A. bambawalei* mated pair provides 25 3rd instar mealybugs for every 2 days and keep separately for parasitoid emergence. The total number of mealybugs parasitized by each parasitoid female during its life span was counted as fecundity.

3.4.1.7 Adult longevity

The longevity of 25 male and female was worked out from the day of emergence to day of death. The average longevity of both the males and females was calculated.

3.4.1.8 Sex ratio

Hundred parasitized mealybugs (cocoons) by *A. bambawalei* were kept in 5.5 cm-diameter Petri dish. After 7

to 8 days the male and female adults emerged from mealybugs were separated for their sexes and sex ratio was worked out.

3.4.2 Mass multiplication of *A. bambawalei*

The studies were conducted on egg laying preference of *A. bambawalei* for different instars of host insect *P. solenopsis* and mass multiplication.

Four host stages of mealybug including three nymphal and one adult were provided to each pair of parasitoids. In this experiment freshly emerged ten males and ten females of adult parasitoids were released in each plastic transparent jar (capacity 15 × 15 × 15 cm) containing 40 mealybugs on sprouted potatoes (comprising ten of each instar and adult) and were confined for 24 h. The parasitoid adults were and provided twenty percent honey solution on cotton swab as a supportive food for parasitoid. The mouth of the jar was covered with muslin cloth. The above experiment was replicated five times. Each parasitized mealybug (cocoons) was detached from these sprouted potatoes after 3 to 4 days and kept in separate transparent box and the number of parasitized instars and adults was counted for recording the egg laying preference, if any, for different instars or adults.

An another experiment was conducted on development and population growth parameters of *A. bambawalei* maintained on mealybug *P. solenopsis* grown on sprouted potatoes at different constant temperature conditions viz. 25±2, 27±2, 30±2 and 32±2 °C in laboratory. The freshly emerged pairs of adult parasitoids from stock culture were placed on mealybugs grown on sprouted potatoes in the parasitoid host ratio of 1:2.5. After parasitization of mealybugs parasitoids *A. bambawalei* were removed. Developmental

duration was determined for each parasitoid. They were monitored daily until parasitoid emergence. During reproductive period parasitized mealybugs were counted and removed daily until all females parasitoid died. The parameters recorded were: larval period, pre-oviposition, oviposition, post-oviposition period, fecundity, male- female longevity and sex ratio.

3.5 Toxicity of different insecticides against *A. bambawalei*.

In this experiment one day old mated parasitoids were used in the experiment from rearing culture. The insecticides used (Table-1) in the present study were obtained as commercially available formulations. Dry film coating technique was followed to assess the toxicity of insecticides to *A. bambawalei*. Only single concentration of each insecticide was prepared using distilled water and used for bioassay. Each replication had ten pairs of parasitoids *A. bambawalei* and there were four replications in each treatment. The glass containers of 20 cm height and 15 cm diameter were cleaned by soaking overnight in soap water, cleaned and rinsed with distilled water. The glass containers were coated evenly with 2 ml of the prepared insecticide solutions and allowed to dry thoroughly. Twenty per cent honey was smeared on a glass cover slip (18 × 18 mm) as supportive food for parasitoid adults and it was gently kept at the bottom of the container. Containers were covered with muslin cloth dipped in the same insecticide solutions and dried. For untreated control 2 ml distilled water was used. Mortality of parasitoid was measured at 1, 3, 6, 12 and 24 h after treatment.

3.5.1 Data analysis

The percentage mortality of the parasitoid *A. bambawalei* in different treatments was transformed to

$\sqrt{(n+1)}$ and statistically analyzed in Completely Randomized Design where, n was equal to mortality percentage of the parasitoid *A. bambawalei*. Appropriate statistical

methods were employed to workout standard error (S.E.) and critical difference (C.D.) for deciding the significance of the treatments (Gomez and Gomez, 1984).

3.6 Activity of *P. solenopsis* on different host plants

Survey was conducted during *Kharif*, 2009 in fields of MPKV, Rahuri campus and road side area of Rahuri and Sangamner tahsils. The objective of the survey was to know the status of mealybug infestation and its parasitization percentage by *A. bambawalei*. Mealybug infestation was recorded at monthly intervals on all identified weed hosts and different cultivated crops along roadsides, crop fallows, barren lands, cultivated fields which were free from pesticide sprays. Individual cotton plants and weeds were inspected for infestation (200 plants) in border rows in all four directions of the field. Host plants were selected at random and all visible stages of the mealybug and mummies of the parasitoid (*A. bambawalei*) were counted on top 10 cm shoot length of main stem and expressed as per cent infestation. Percent plant infestation was calculated by total number of plants inspected in each host. After counting, the 10 cm portion of infested cotton shoots along with mealybug colonies, infested plant parts of weed hosts and crops plants were cut and brought to the laboratory for enumeration of third instar nymphs and adult mealybugs. They were kept in the plastic jars in wooden cages at 25 ± 2 °C, 65 ± 5 RH for parasitoid emergence from parasitized mealybugs. The individual jars were covered with muslin cloth. Samples were retained in the jar and observed daily for parasitoid emergence till 15 days after collection. Parasitoid count was converted to percent parasitization with reference to initial count of the mealybug.

3.7 Evaluation of different chemical insecticides and biopesticides for the management of *P. solenopsis*

Design of experiment

Design	: Randomized Block
Design	
Replications	: Four
Treatments	: Fourteen
Crop	: Cotton
Variety	: <i>Bt</i> RCH-2
Spacing	: 90 x 60 cm
Plot size	: 7.20 x 6.00 m

Field experiment was conducted during *Kharif*, 2008 and 2009 to evaluate the efficacy of insecticides and biopesticides against *P. solenopsis* on *Bt* cotton *var.* RCH-2 *Bt* at Instructional farm of Post Graduate Institute, MPKV, Rahuri (Plate 7). The experiment was laid out in a randomized block design with fourteen treatments. The crop was sown in the month of June in both the seasons and all other recommended cultural practices were followed. Irrigation was given four times during the cropping season. In both the years, the experiment was replicated four times in plots of 7.20 x 6.00 m size with a spacing of 90 x 60 cm between row to row and plant to plant. Five plants were randomly selected and tagged for observations. In both the years, agronomic practices were followed as per the recommended package of practices (Anonymous, 2008). Two rounds of common sprays were taken to combat early sucking pests of cotton in both the years and two rounds of treatments were imposed. Treatments were applied when 10 per cent mealybug population was observed in the experimental block

(Plate 8). Mealybugs were recorded on top apical shoot and the data were presented as number of mealybugs/10 cm shoot length. Observations were recorded a day before spray and three, seven, ten and 14 days after spray. The insecticides used (Table-1) in the present study were obtained as commercially available formulations.

The details of the treatments during *Kharif*, 2008 and 2009 seasons are given in Table-1.

Table 1. Treatment details

Sr. No.	Treatments	Concentration	Dose (g or ml/ha)	Manufactured by
1	Neem oil (Neem care)	0.03% EC	2000	Cheminova Agrotech, Mumbai.
2	NSKE	5%	25000	Locally prepared
3	<i>Verticillium lecanii</i> (Phule Bugicide)	1×10^8 CFU/g	2000	Mahatma Phule Krishi Vidyapeeth, Rahuri.
4	<i>Metarrhizium anisopliae</i> (Phule <i>metarrhizium</i>)	1×10^8 CFU/g	2000	Mahatma Phule Krishi Vidyapeeth, Rahuri
5	<i>Beauveria bassiana</i> (Phule <i>Beauveria bassianna</i>)	1×10^8 CFU/g	2000	Mahatma Phule Krishi Vidyapeeth, Rahuri
6	Dichlorvos (Nuvan)	76 EC	1000	Syngenta India Ltd., Pune
7	Clothianidin (Dantop)	50 WDG	150	Nagarjuna Agri Chemicals, Hyderabad
8	Buprofezin (Applaud)	25 SC	1250	Rallis India Ltd., Banglore
9	Profenophos (Curacron)	50 EC	1500	Syngenta India Ltd., Pune
10	Imidacloprid (Confidor)	17.8 SL	200	Bayer Crop Science, Mumbai
11	Thiamethoxam (Actara)	25 WG	200	Syngenta India Ltd. Pune

12	Triazophos (Hostathion)	40 EC	625	Bayer Crop Science, Mumbai
13	Chlorpyrifos (Dursban)	20 EC	1500	Dow Agro India Ltd., Mumbai
14	Untreated control	--	--	--

3.8 Preparation of working concentrations

3.8.1 Insecticides

The working concentrations of each of the insecticides were worked out by using following formula.

$$C_1 \times V_1 = C_2 \times V_2$$

Where,

C_1 = Active ingredient in commercial product

V_1 = Quantity of insecticide required

C_2 = Required spray concentration

V_2 = Volume of spray required

3.8.2 Neem seed kernel extract (NSKE)

Fifty gram of neem seed powder was soaked for overnight in 1000 ml of water, next morning the seed powder was squeezed using muslin cloth and volume of extract was adjusted to one litre by addition of clean water (Pradhan *et al.*, 1962) to prepare 1 litre 5% NSKE solution.

3.8.3 Data analysis

Survival population of the mealybug in different treatments was transformed to $\sqrt{(n+1)}$ and statistically analyzed in RBD where, n was equal to count of live population of mealybugs. The analysis of pooled data of two seasons (*Kharif*, 2008 and 2009) was carried out to ascertain the relative efficacy of the insecticide treatments against cotton mealybug. Appropriate statistical methods were employed to workout

standard error (S.E.) and critical difference (C.D.) for deciding the significance of the treatments (Gomez and Gomez, 1984).

4. EXPERIMENTAL RESULTS

The results of the experiments conducted on the following objectives viz., study on the biology of cotton mealybug, *Phenacoccus solenopsis* (Tinsley) and its parasitoid (*Aenasius bambawalei* Hayat); mass production of cotton mealybug and its parasitoid (*A. bambawalei*) and evaluation of different chemical insecticides and biopesticides for the management of cotton mealybug, *P. solenopsis* are presented hereunder.

4.1 Biology of mealybug, *P. solenopsis*

The data on morphometrics of different life stages of *P. solenopsis* are presented in Table 2 and other biological parameters in Table 3.

4.1.1 Measurement of different life stages of *P. solenopsis* in laboratory conditions

Twenty five individuals were observed for each of the parameters. Biology of *P. solenopsis* was studied under laboratory conditions on potato sprout at room temperature $25 \pm 2^{\circ}\text{C}$ with a relative humidity 65 ± 5 per cent during *Kharif*, 2008 and results are presented in Table 2.

4.1.1.1 Eggs

Cotton mealybug *P. solenopsis* female produced an ovisac at posterior ventral end of the body with the help of wax threads by wax gland and eggs were thrust into ovisac. The ovisacs were dirty white in colour. The eggs were laid in mass in a loose cottony ovisac. They were closely held with each other within the ovisac. Freshly laid eggs were orange in colour, smooth and oval in shape with slightly tapering ends (Plate 9). The length of egg was in between 0.40 to 0.50 mm (mean 0.45 ± 0.02 mm) and the width ranged from 0.18 to 0.24 mm (mean

0.21 ± 0.02 mm). The female deposited eggs in the ovisacs for 2 to 3 days continuously when left undisturbed. During this period, most of the eggs hatched and the crawlers remained inside the ovisacs along with freshly laid eggs.

4.1.1.2 Nymphal instars

i. First instar

Newly hatched crawlers were quite mobile. First instar nymphs were oblong in shape, pale yellow in colour, flattened ventrally with three pairs of well developed legs. They settled on the potato sprout and started developing. First instar nymph measured 0.61 ± 0.04 mm (range 0.55 to 0.66 mm) in length and 0.29±0.02 mm (range 0.26 to 0.33 mm) in width.

ii. Second instar

Freshly moulted second instar nymphs were similar to the first instar nymphs in general appearance and morphological characters, except enlarged body size. The second instar measured 1.30±0.17 mm (range 0.90 to 1.63 mm) in length and 0.63±0.08 mm (range 0.50 to 0.75 mm) in width. After 24 h of the first moulting, the white waxy powder over its body was quite prominent.

iii. Third instar

Freshly emerged third instar nymphs were yellow in colour and oblong in shape. Third instar full grown female nymph measured 2.13±0.06 mm (range 2.00 to 2.20 mm) in length and 1.74±0.02 mm (range 1.70 to 1.78 mm) wide. Two black spots on thoracic region and two black stripes on abdomen were prominent. However, after 24 h the nymphs secreted white wax on dorsal side and white waxy filaments laterally giving them grayish appearance with 18 pairs of lateral filaments. Among first, second and third instars, the first two instars were

more active and had tendency to settle on tender shoot of potato sprouts. Third instar nymph and adult female did not move much once they established at feeding site.

4.1.1.3 Pupa (cocoon)

During the first two nymphal instars it was difficult to differentiate between male and female nymph. The full grown second instar male started spinning a white cocoon in which it pupated. Males produced cocoon (puparia) over their bodies. It measured 1.85 ± 0.03 mm (range 1.80 to 1.90 mm) in length and 0.54 ± 0.03 mm (range 0.50 to 0.60 mm) in width.

4.1.1.4 Adult female

Adult females were wingless and oval to oblong in shape, secreting white wax on dorsal side and white waxy filaments laterally giving them greyish appearance with 18 pairs of lateral filaments (Plate 10). However, when wax was removed, the body was observed to be yellow in colour with two black spots on thorax and two black stripes on the abdomen. Within two days from formation of adult female the body was covered with white waxy secretion, except over the black spots and stripes. Due to wax secretion, the body appeared somewhat raised while the black spots and stripes appeared as depressions over the body. Adult female measured 3.90 ± 0.06 mm (range 3.80 to 4.00 mm) in length and 2.05 ± 0.04 mm (range 2.00 to 2.11 mm) in width. There were 18 pairs of lateral wax filaments around the body and the posterior end possessed the longest pair of filaments compared to others. The legs were purple in colour.

4.1.1.5 Adult male

Male and female nymphs were indistinguishable up to 2nd instar; but after second instar it was possible to differentiate the sexes.

Adult male were slender, delicate, smoky brown in colour and elongate in shape having single pair of well developed milky white mesothoracic wing and three pairs of well developed legs. Males were 1.10 ± 0.06 mm (range 1.00 to 1.20 mm) and 0.20 ± 0.02 mm (range 0.18 to 0.24 mm) in length and width, respectively. Four waxy filaments were present at anal end.

4.1.2 Developmental parameters of *P. solenopsis* on potato sprouts under laboratory conditions

The data on developmental parameters of *P. solenopsis* on potato sprouts under laboratory condition is presented in Table 3.

4.1.2.1 Egg

The eggs were laid in ovisacs and incubation period occupied 1.25 to 5 minutes with a mean of 2.92 ± 1.11 minutes.

4.1.2.2 Nymphal instars

Development of first, second and third nymphal instars of female was completed in 4.84 ± 0.75 , 6.22 ± 1.19 and 4.76 ± 0.91 days, respectively. Male had two nymphal instars with a mean duration of 4.60 ± 0.87 and 7.42 ± 1.55 days, respectively for first and second instar crawlers.

4.1.2.3 Male pupal period

Pupal period of male was completed in 5 to 9 days with mean of 7.20 ± 1.32 days.

4.1.2.4 Adult male

After emergence from pupa, the adult male development was completed in 12 to 24 days with a mean of 19.22 ± 3.34 days.

Table 2. Measurement of different life stages of *P. solenopsis* in laboratory conditions*

Life stage	Length (mm)		Width (mm)	
	Mean±SD	Range	Mean±SD	Range
Egg	0.45±0.02	0.40-0.50	0.21±0.02	0.18-0.24
First instar	0.61±0.04	0.55-0.66	0.29±0.02	0.26-0.33
Second instar	1.30±0.17	0.72-0.78	0.63±0.08	0.50-0.75
Third instar	2.13±0.06	2.00-2.20	1.74±0.02	1.70-1.78
Pupa(cocoon)	1.85±0.03	1.80-1.90	0.54±0.03	0.50-0.60
Adult female	3.90±0.06	3.80-4.00	2.05±0.04	2.00-2.11
Adult male	1.10±0.06	1.00-1.20	0.20±0.02	0.18-0.24

* Temperature: 25±2 °C, RH: 65±5 %

Table 3. Developmental parameters of *P. solenopsis* under laboratory conditions*

Biological developmental parameters	Duration (days)	
	Mean + SD	Range
Incubation period (minutes)	2.92±1.11	1.25-5
A. Female		
First instar	4.84±0.75	3-6
Second instar	6.22±1.19	4-9
Third instar	4.76±0.91	4-7
Nymphal duration (days)	15.82 ± 2.85	11-22
Pre-oviposition period(days)	3.78±0.69	3-5
Oviposition period(days)	14.28±1.65	11-17
Post-oviposition period(days)	2.96±0.68	2-4
Fecundity (No. of crawlers laid/female)	594.84±64	312-860

Ovisacs (No. of ovisacs /female)	5.72 $\pm$ 1.02	4-7
Adult longevity(days)	17.16 $\pm$ 2.33	14-23
Total life cycle (days)	36.84 $\pm$ 5.87	25-42
B. Male		
First instar	4.60 $\pm$ 0.87	3-6
Second instar	7.42 $\pm$ 1.55	4-9
Nymphal duration(days)	12.02 $\pm$ 2.42	7-15
Pupal period (days)	7.20 $\pm$ 1.32	5-9
Adult longevity(days)	2.08 $\pm$ 0.59	1-3
Total life cycle (days)	21.30 $\pm$ 4.33	12-25
Sex ratio (male: female)	1:3	--

* Temperature: 25 $\pm$ 2 $^{\circ}$ C, RH: 65 $\pm$ 5 %

4.1.2.5 Adult longevity

The adult longevity of female varied from 14 to 23 days with the mean value of 17.16 $\pm$ 2.33 days and male longevity was 2.08 $\pm$ 0.59 days with the range of 1 to 3 days. Mean life duration of female was 36.84 $\pm$ 5.87 with the range of 25 to 42days. While, male was 21.30 $\pm$ 4.33 with the range of 12 to 25 days. The female deposited 4 to 7 egg sacs (mean 5.72 $\pm$ 1.02) during its life from which 312-860 crawlers (mean 594.84 $\pm$ 64) were emerged. Pre-oviposition, oviposition and post oviposition periods of adult female were 3.78 $\pm$ 0.69, 14.28 $\pm$ 1.65 and 2.96 $\pm$ 0.68 days, respectively. Male to female sex ratio in the progeny was 1:3.

4.2 Biology of *A. bambawalei*

The data on morphometrics of different life stages of mealybug parasitoid, *A. bambawalei* are presented in Table 4. and other biological parameters in Table 5. Twenty five individuals were observed for each parameter.

4.2.1 Measurement of different life stages of *A. bambawalei* in laboratory conditions

Egg and larval stages of the parasitoid were not visible being an internal feeder, but swelling and poor movements of parasitized mealybug were observed after 3 to 4 days of parasitization. The parasitized mealybug transformed into dark brown mummies within 4 to 8 days after parasitization.

Parasitized mealybug transformed into dark brown mummy (cocoon) within 4 to 8 days (Plate 11). Cocoons of parasitoid were barrel shape with dark brown colour. The length and width of parasitoid pupae ranged from 3.20 to 3.45 mm and 1.70 to 1.85 mm with a mean of 3.37 ± 0.06 mm and 1.78 ± 0.05 mm, respectively (Table 4).

Adults of parasitoid emerged out by cutting a circular small hole on mummies (pupae) after completion of pupal period (Plate 11). Antennae were covered with small hair like structures. The apex of antennae was club like with light black colour. Male and females of *A. bambawalei* were separated by their morphological characters. Female of parasitoid was bigger than male (Plate 12). Head of male was somewhat dumb-bell shaped, small and attached narrowly with the thorax, whereas in female it was somewhat oval shaped, thorax slightly larger and broadly attached with it. Adults of both the sexes were blackish in colour. The female body was shiny black in colour with large thimble like setigerous punctures on head. In case of male thimble like punctures were more or less similar as in female. Length and width of male ranged from 1.00 to 1.40 and 0.30 to 0.45 mm with an average of 1.20 ± 0.12 mm and 0.39 ± 0.04 mm respectively, whereas in females it ranged from 1.40 to 2.10 and 0.65-0.85 mm

with mean of 1.81 ± 0.21 and 0.78 ± 0.05 mm, respectively. Head width of male ranged from 0.40 to 0.64 mm with a mean of 0.44 ± 0.05 mm, while in females it was 0.70 to 0.90 mm with a mean of 0.84 ± 0.05 mm.

Table 4. Measurement of different life stages of *A. bambawalei* in laboratory conditions*

Life stage	Length (mm)		Width (mm)	
	(Mean $\pm$ SD)	Range	(Mean $\pm$ SD)	Range
Pupa	3.37 ± 0.06	3.20-3.45	1.78 ± 0.05	1.70-1.85
Adult female	1.81 ± 0.21	1.40-2.10	0.78 ± 0.05	0.65-0.85
Head width	--	--	0.84 ± 0.05	0.70-0.90
Adult male	1.20 ± 0.12	1.00-1.40	0.39 ± 0.04	0.30-0.45
Head width	--	--	0.44 ± 0.05	0.40-0.64

Table 5. Developmental parameters of *A. bambawalei* under the laboratory conditions*

Biological parameters	Duration (days)	
	Mean $\pm$ SD	Range
A. Female		
Larval period (days)	5.68 ± 0.99	4-8
Pupal period (days)	7.48 ± 1.23	6-10
Development of female (days)	15.16 ± 1.57	13-18
Oviposition period (days)	24.04 ± 4.34	15-31
Post-oviposition period (days)	3.07 ± 0.96	1-5
Fecundity (No. of parasitized mealybugs/female parasitoid)	83.48 ± 34.62	25-155
Adult longevity (days)	27.11 ± 5.31	16-36
Total life cycle (days)	40.27 ± 7.52	26-54
B. Male		
Larval period (days)	5.86 ± 0.93	4-7
Pupal period (days)	5.44 ± 1.08	4-7

Development of male (days)	11.54 $\pm$ 1.81	10-13
Adult longevity (days)	6.49 $\pm$ 1.16	5-8
Total life cycle (days)	17.79 $\pm$ 3.17	13-22
Sex ratio (male:female)	1:2	--

*Temperature: 25 $\pm$ 2 °C, RH: 65 $\pm$ 5 %

4.2.2 Developmental parameters of *A. bambawalei* under the laboratory conditions

The data on biological parameters of *A. bambawalei* under the laboratory conditions are presented in Table 5. Twenty five individuals were observed for each of the parameters.

A. bambawalei is solitary endoparasitoid and oviposits eggs into mealybug body through ventral surface of the body and completes its life cycle in the mealybug body causing mealybug to swell and change its colour to light brown. The developing larva at the later stage turns the mealybug into legless, brown, barrel shaped pupa with dark brown colour. Pupa of parasitoid was kidney bean shaped called mummy. Larval duration of female and male parasitoid was 5.68 $\pm$ 0.99 days (range 4 to 8) and 5.86 $\pm$ 0.93 days (range 4 to 7), respectively.

Female and male pupal periods were 7.48 $\pm$ 1.23 and 5.44 $\pm$ 1.08 days with the range of 6 to 10 and 4 to 7 days, respectively. The development of the female and male parasitoid from the date of parasitization till its emergence from pupa took 13 to 18 and 10 to 13 days with average days of 15.16 $\pm$ 1.57 and 11.54 $\pm$ 1.81 days, respectively. However, adult female and male longevity was 27.11 $\pm$ 5.31 and 6.49 $\pm$ 1.16 days with range from 16 to 36 and 5 to 8 days, respectively. Oviposition and post oviposition period of female was 24.04 $\pm$ 4.34 and 3.07 $\pm$ 0.96 days with the range from 15 to 31 and 1 to 5 days, respectively.

Twenty five 3rd instar mealybugs were exposed to one mated female parasitoid in a jar for 48 hours. The same female

parasitoid was then removed from the jar and released in another jar containing 25 3rd mealybugs. This was repeated for mean of 24.04 ± 4.34 days. Parasitoid parasitized about 25 to 155 mealybugs (3rd instar) with mean of 83.48 ± 34.62 mealybugs in its life. Egg laying capacity per female was estimated on the basis of number of parasitized mealybugs from those exposed to one pair of the parasitoid in its life. Male and female sex ratio of parasitoid in the progeny was 1:2.

4.3 Mass production of *P. solenopsis*

The data on effect of different host plants on growth and development of *P. solenopsis* are presented in Table 6 and development of *P. solenopsis* at different temperatures under laboratory conditions are given in Table 7.

4.3.1 Effect of different host plants on growth and development of *P. solenopsis*

The data on variations among three host plants with respect to biological parameters were presented in Table 6. Twenty five individuals were observed for each of the parameter. Maximum individuals (87.50 %) reached to adult in potato sprout, followed by *Hibiscus* (80.83%) and cotton (79.16%). Total nymphal period on cotton, *Hibiscus* and potato were 16.78 ± 2.65 , 17.66 ± 2.41 and 15.82 ± 2.66 days, respectively. The average pre-oviposition, oviposition and post-oviposition periods were observed to be 5.16 ± 0.75 , 10.44 ± 1.94 and 2.64 ± 0.49 days on cotton, 4.92 ± 0.76 , 12.40 ± 1.68 and 2.84 ± 0.37 days on *Hibiscus* and 3.78 ± 0.69 , 14.28 ± 1.65 and 2.96 ± 0.68 days on sprouted potato, respectively. Maximum fecundity of the mealybug was recorded on potato sprouts (594.84 ± 163.65 crawlers) followed by *Hibiscus* (492.8 ± 110.92 crawlers) and cotton (481.6 ± 92.32 crawlers). However, female longevity was 21.02 ± 2.34 days on potato followed by 20.16 ± 2.44 days on *Hibiscus* and 18.24 ± 2.18 days on cotton. Similarly male longevity was noticed 2.08 ± 0.59 days on potato, followed by 1.92 ± 0.75 days on *Hibiscus* and 1.76 ± 0.77 days on cotton. Sex ratio

(male: female) was recorded 1:3, 1:3 and 1:2.2 on cotton, potato sprouts and *Hibiscus*, respectively.

Table 6. Effect of different host plants on growth and development of *P. solenopsis**

Sr. No	Biological Parameters	Different hosts (Mean $\pm$ SD)		
		Cotton plant	<i>Hibiscus chinensis</i>	Potato sprouts
1	No.of individuals (nymph) released on each host plant	120	120	120
2	No.of individuals reaching adult stage (%)	95 (79.16)	97 (80.83)	105 (87.50)
3	Crawler I st instar (days)	4.60 $\pm$ 0.74 (3-5.5)*	5.08 $\pm$ 0.59 (3-6)	4.84 $\pm$ 0.75 (3-6)
4	Crawler II nd instar (days)	6.18 $\pm$ 1.07 (4-7)	6.34 $\pm$ 1.09 (4-8)	6.14 $\pm$ 1.06 (4-7)
5	Crawler III rd instar (days)	6.00 $\pm$ 1.81 (4-9)	6.24 $\pm$ 1.94 (4.5-10)	4.84 $\pm$ 1.22 (4-9)
6	Total nymphal period (days)	16.78 $\pm$ 2.65 (11-21.5)	17.66 $\pm$ 2.41 (11.50-24)	15.82 $\pm$ 2.66 (11-22)
7	Pre oviposition period (days)	5.16 $\pm$ 0.75 (4-6)	4.92 $\pm$ 0.76 (4-6)	3.78 $\pm$ 0.69 (3-5)
8	Oviposition period (days)	10.44 $\pm$ 1.94 (8-13)	12.40 $\pm$ 1.68 (10-15)	14.28 $\pm$ 1.65 (11-17)
9	Post oviposition period (days)	2.64 $\pm$ 0.49 (2-3)	2.84 $\pm$ 0.37 (2-3)	2.96 $\pm$ 0.68 (2-4)
10	Fecundity (No. of eggs laid /female)	481.6 $\pm$ 92.32 (350-630)	492.8 $\pm$ 110.92 (380-720)	594.84 $\pm$ 163.65 (312-860)
11	Female longevity (days)	18.24 $\pm$ 2.18 (14-22)	20.16 $\pm$ 2.44 (16-24)	21.02 $\pm$ 2.34 (16-26)
12	Pupal period (days)	7.20 $\pm$ 1.32 (5-9)	7.50 $\pm$ 1.22 (5.5-9)	7.20 $\pm$ 1.32 (5-9)
13	Male longevity (days)	1.76 $\pm$ 0.77 (1-3)	1.92 $\pm$ 0.75 (1-3)	2.08 $\pm$ 0.59 (1-3)
14	Sex ratio (male:female)	1:3	1:2.2	1:3

* Figures in parentheses indicate the range.

Temperature: 25 $\pm$ 2 °C, RH: 65 $\pm$ 5 %

4.3.2 Development of *P. solenopsis* at different constant temperatures under laboratory conditions

The data presented in Table 7 indicated variation on different biological parameters studied at test temperatures. Total nymphal periods at 25 ± 2 , 27 ± 2 , 30 ± 2 and 32 ± 2 °C and relative humidity 65 ± 5 per cent were 16.44 ± 2.74 , 16.25 ± 2.29 , 15.75 ± 1.83 and 16.02 ± 2.36 days, respectively. The average pre-oviposition, oviposition and post-oviposition periods were observed to be 5.24 ± 0.66 , 10.96 ± 2.17 and 2.72 ± 0.46 days at 25 ± 2 °C, 4.96 ± 0.61 , 10.24 ± 1.69 and 2.52 ± 0.51 days at 27 ± 2 °C, 4.68 ± 0.69 , 9.72 ± 1.95 and 2.36 ± 0.49 days at 30 ± 2 °C and 4.28 ± 0.94 , 9.20 ± 1.61 and 2.08 ± 0.76 days at 32 ± 2 °C, respectively. Maximum fecundity was recorded at 25 ± 2 °C (487.60 ± 92.34) followed by decline in fecundity with increasing temperature; i.e. 466.40 ± 89.30 at 27 ± 2 °C, 442 ± 97.38 at 30 ± 2 °C and 410.80 ± 87.51 at 32 ± 2 °C. However, female longevity was maximum 18.92 ± 2.06 at 25 ± 2 °C, and then decreased with increasing temperature i.e. 17.72 ± 1.72 days at 27 ± 2 °C, 16.76 ± 1.71 days at 30 ± 2 °C and 15.56 ± 1.51 days at 32 ± 2 °C. Similarly male longevity was higher 2.40 ± 0.58 days at 25 °C and then decreased with increasing temperature 2.12 ± 0.60 days at 27 ± 2 °C, 1.92 ± 0.70 days at 30 ± 2 °C and 1.76 ± 0.78 days at 32 ± 2 °C days. Sex ratio (male: female) was recorded 1:3, 1:3, 1:3 and 1:2.3 at 25 ± 2 , 27 ± 2 , 30 ± 2 and 32 ± 2 °C, respectively.

4.4 Mass multiplication of *A. bambawalei*

4.4.1 Preference of *A. bambawalei* to different stages of mealybug, *P. solenopsis*

The result regarding the host stage preference of *A. bambawalei* showed that maximum parasitization percentage (91.00 %) was recorded on third instar nymph followed by adult

Table 7. Development of *P. solenopsis* at different temperatures under laboratory conditions*

Biological Parameters	Different temperature conditions			
	25±2 °C	27±2 °C	30±2 °C	32±2 °C
Total nymphal period (days)	16.44±2.74 (12-21)*	16.25±2.29 (10.50-18)	15.75±1.83 (10-17)	16.02±2.36 (11-19)
Preoviposition period (days)	5.24±0.66 (4-6)	4.96±0.61 (4-6)	4.68±0.69 (4-6)	4.28±0.94 (3-5)
Oviposition period (days)	10.96±2.17 (8-14)	10.24±1.69 (8-12)	9.72±1.95 (7-12)	9.20±1.61 (7-11)
Post oviposition period (days)	2.72±0.46 (2-3)	2.52±0.51 (2-3)	2.36±0.49 (2-3)	2.08±0.76 (1-3)
Fecundity (No. of eggs laid /female)	487.60±92.34 (320-620)	466.40±89.30 (280-590)	442±97.38 (260-570)	410.80±87.51 (230-520)
Female longevity (days)	18.92±2.06 (12-18)	17.72±1.72 (12-17)	16.76±1.71 (11-16)	15.56±1.51 (11-15)
Male longevity (days)	2.40±0.58 (1-3)	2.12±0.60 (1-3)	1.92±0.70 (1-3)	1.76±0.78 (1-3)
Sex ratio (male:female)	1:3	1:3	1:3	1:2.3

* Figures in parentheses indicate the range. *RH: 65±5 % mealybug (81.20%), second instar nymph (31.00%), while no parasitization was observed in first instar nymph of mealybug (Fig.1). Parasitoid preferred mostly 3rd instar host insect and adult for parasitization. Sex ratio of parasitoid male to female

was (3:2) on second instar mealybug. However, sex ratio of male to female was 1:1.5 on third instar and 1:2 on adult mealybug (Table 8).

4.4.2 Development of *A. bambawalei* at different temperatures under laboratory conditions

The data in (Table 9) revealed that there was variation in different biological parameters studied at test temperatures. Total larval periods of parasitoid at 25±2, 27±2, 30±2 and 32±2°C and relative humidity 65±5 per cent were 6.0 ± 1.12, 5.80 ± 1.05, 5.84 ± 1.00 and 5.58 ± 1.91 days, respectively. The average oviposition and post-oviposition periods were observed to be 24.72 ± 4.37 and 3.27 ± 1.03 days at 25±2°C, 24.20 ± 4.61 and 3.19 ± 1.05 days at 27±2°C, 24.08 ± 3.91 and 2.95 ± 0.95 days at 30±2°C and 22.80 ± 4.81 and 2.73 ± 0.57 days at 32±2°C. Maximum fecundity, 88.36 ± 33.80 was recorded at 25±2°C, whereas it decreased with increasing temperature; i.e. 86.36 ± 32.72 at 27±2°C, 85.84 ± 30.67 at 30±2°C and 83.48 ± 27.36 at 32±2°C. The female longevity was maximum 27.99 ± 6.42 days at 25±2°C and then decreased with increasing temperature i.e. 27.39 ± 5.43 days at 27±2°C, 27.03 ± 4.92 days at 30 ±2°C and 25.53 ± 4.37 days at 32±2°C. Similarly, male longevity was higher at 25±2°C i.e. 6.73 ± 1.13 days and then decreased with increasing temperature 6.54 ± 0.98 days at 27±2°C, 6.25 ± 1.36 days at 30±2°C and 5.86 ± 0.67 days at 32±2°C. The sex ratio was 1:2 at 25±2 and 27±2°C, while 1:1.5 at 30±2 and 32±2°C.

Table 8. Preference of *A. bambawalei* to different stages of mealybugs, *P. solenopsis*

Stage of mealybug	Per cent parasitization						Sex ratio
	RI (%)	RII (%)	RIII (%)	RIV (%)	RV (%)	Mean (%)	
1 st instar	0	0	0	0	0	0.00	----
2 nd instar	27	31	33	29	35	31.00	3:2.0
3 rd instar	68	75	86	91	86	81.20	1:1.5
Adults	88	90	92	91	94	91.00	1:2.0

* Temperature: 25±2 °C, RH: 65±5 %

Table 9. Development of *A. bambawalei* at different temperatures under laboratory condition

Biological parameters	Temperature conditions			
	25±2 °C	27±2 °C	30±2 °C	32±2 °C
Larval duration (days)	6.0±1.12 (5.0- 8.0)*	5.80±1.05 (5.0-8.0)	5.84±1.00 (5.0-7.0)	5.58±1.91 (5.0-7.0)
Oviposition period (days)	24.72±4.37 (17-32)	24.20±4.61 (17-30)	24.08±3.91 (16-28)	22.80±4.81 (14-28)
Post oviposition period (days)	3.27±1.03 (1.0-5.0)	3.19±1.05 (1.0-5.0)	2.95±0.95 (1.0-4.0)	2.73±0.57 (1.0-3.0)
Female pupal period (days)	6.16±0.90 (5.0-7.0)	6.00±0.91 (5.0-7.0)	5.16±1.07 (5.0-7.0)	6.08±0.86 (5.0-7.0)
Male pupal period (days)	5.04±0.89 (4.0-7.0)	4.88±0.88 (4.0-6.0)	4.88±0.78 (4.0-6.0)	4.64±0.49 (3.0-5.0)
Fecundity (No. of mealybugs parasitized)	88.36±33.80 (45-160)	86.36±32.72 (40-145)	85.84±30.67 (40-130)	83.48±27.36 (35-120)
Female longevity (days)	27.99±6.42 (12.0-31)	27.39±5.43 (11.0-28)	27.03±4.92 (11.0-26.0)	25.53±4.37 (11.0-25)
Male longevity (days)	6.73±1.13 (5.0-8.0)	6.54±0.98 (5.0-7.0)	6.25±1.36 (4.0-7.0)	5.86±0.67 (4.0-6.0)
Sex ratio	1:2	1:2	1:1.5	1:1.5

*Figures in parentheses indicate the range. RH: 65±5 %

4.5 Activity of *P. solenopsis* on different host plants and its parasitization

Field surveys were undertaken in September, October and November months during 2009 to assess the occurrence of mealybug, *P. solenopsis* and its parasitoid, *A. bambawalei* on

cotton and associated weeds. Cotton and nine weed host plants were found to be infested (Plate 13) with *P. solenopsis* and parasitization of mealybug by *A. bambawalei* (Table 10) was also observed. Two hundred plants of each host were observed. The per cent infestation of mealybug varied in different months. During September infestation was found more on *Hibiscus* (48.00%) followed by *Mesta* (34.50%), *Gossypium* (26.00%) and lowest on *Xanthium* (8.50%). Infestation of mealybug was increased in October month and it was highest on *Hibiscus* (61.50%) followed by *Mesta* (60.50%), *Gossypium* (28.50%) and *Acalypha* (28.00%), whereas it was minimum on *Xanthium* (5.50%). In November month, maximum infestation was found on *Hibiscus* (39.50%) and lowest on *Amaranthus* (4.50%) .

The highest parasitization of mealybug by *A. bambawalei* was found on *Hibiscus* (10.22%) followed by *Mesta* (8.00%) and *Parthenium* (7.77%) and minimum on *Ephorbia geniculata* (3.72%) in September. However, in October maximum parasitization was found on *Hibiscus* (7.89%) followed by *Mesta* (7.69%) and minimum on *Parthenium* (5.48%) while in November maximum parasitization was found on *Mesta* (10.00%) followed by *Hibiscus* (7.50%) and minimum on *Lantana* (2.85%). No infestation was found on *Xanthium* in November.

Table 10. Activity of *P. solenopsis* on different host plants and its parasitization

Host plants	% plant infested by <i>P. solenopsis</i> (n=200)			% Parasitization by <i>A. bambawalei</i>		
	September	October	November	September	October	November
<i>Mesta Hibiscus cannabinus</i> L.	34.50	60.50	25.50	8.00 (350)*	7.69 (260)	10.00 (130)
<i>Hibiscus rosa sinensis</i> L.	48.00	61.50	39.50	10.22 (450)	7.81 (320)	7.50 (160)
<i>Gossypium spp.</i>	26.00	28.50	10.50	8.21 (280)	7.05 (312)	5.88 (85)
<i>Acalypha indica</i> L.	23.50	28.00	17.50	7.06 (170)	7.61 (210)	6.25 (80)
<i>Parthenium hystererophorus</i>	25.00	24.50	25.50	7.77 (90)	5.48 (146)	4.30 (93)
<i>Ephorbia geniculata</i> L.	16.00	21.50	8.00	3.72 (430)	7.62 (420)	6.31 (380)
<i>Xanthium strumarium</i> L.	8.50	5.50	--	5.35 (56)	5.88 (85)	--
<i>Amaranthus viridis</i> L.	14.50	16.00	4.50	4.76 (42)	7.50 (80)	5.00 (60)
<i>Lantana camara</i> L.	18.50	34.00	9.50	4.21 (95)	5.18 (135)	2.85 (70)

<i>Abelmoschus esculentum</i>	22.5 0	46.00	29.50	5.90 (220)	6.28 (350)	3.07 (130)
Mean	24.7 0	33.60	17.00	6.52	7.03	5.11

* Figure in parenthesis represents number of mealybug

4.6 Toxicity of different insecticidal treatments against *A.bambawalei*

After exposure of *A. bambawalei* to treated petriplates 1, 3, 6, 12 and 24 h (Table 11), zero per cent mortality was observed in *Verticillium*, *Beauveria*, *Metarrhizium* and buprofezin treatments in case of female and male. Moderate to high mortality was noticed after 1h in NSKE (50.00%), clothianidin (85.00%), imidacloprid (82.50%) and thiamethoxam (85.00%) treatments in both female and male parasitoids. However, 42.50 per cent mortality of female parasitoid and 45.00 per cent mortality of male in neem oil were observed which was slightly high than females. Dichlorvos, profenophos, triazophos and chlorpyrifos caused 100% mortality within 1h in both sexes (Table 11).

Similarly, moderate to high mortality of *A. bambawalei* female and male after 3 h exposure was observed as 52.50 per cent and 62.50 per cent in neem oil. The female and male mortality in respective treatments was 60.00 and 67.50 per cent in NSKE, 70.00 and 87.50 per cent in imidacloprid, 82.50 and 92.50 per cent in thiamethoxam, 87.50 and 92.50 per cent in clothianidin, respectively. Whereas, female and male mortality after 6 h in various treatment was 62.50 and 72.50 per cent in neem oil, 70.00 and 75.00 per cent in NSKE, 85.00 and 100.00 per cent in imidacloprid, 92.50 and 100.00 per cent in clothianidin, 100.00 per cent in thiamethoxam, respectively, while, female and male mortality after 12 h in various treatment was 75.00 and 92.50 per

cent in neem oil, 77.50 and 87.50 per cent in NSKE, 100.00 per cent in imidacloprid, 100 per cent in clothianidin and 100.00 per cent in thiamethoxam, profenophos, triazophos, chlorpyriphos respectively. The mortality after 24 h in both the sexes was 100 per cent in neem oil, NSKE, imidacloprid, clothianidin and thiamethoxam (Table 11) (Fig.2 and 3).

Table 11. Effect of different insecticides on mortality of *A. bambawalei*

Sr. No.	Treatments	Dosage ml or g/lit.	% Mortality of <i>A. bambawalei</i> after different hour exposure									
			1 h		3 h		6 h		12 h		24 h	
			Female	Male	Female	Male	Female	Male	Female	Male	Female	Male
1.	Neem oil 0.03% EC	4	42.50 (40.61)*	45.00 (42.05)	52.50 (46.44)	62.50 (52.49)	62.50 (52.34)	72.50 (58.45)	75.00 (60.64)	92.50 (78.75)	100.00 (90.00)	100.00 (90.00)
2.	NSKE 5%	50	50.00 (44.94)	50.00 (44.94)	60.00 (50.89)	67.50 (55.44)	70.00 (56.95)	75.00 (60.11)	77.50 (62.14)	87.50 (72.48)	100.00 (90.00)	100.00 (90.00)
3.	<i>V. lecanii</i>	4	0.00 (6.42)	0.00 (6.42)	0.00 (6.42)	0.00 (6.42)	0.00 (6.42)	0.00 (6.42)	0.00 (6.42)	0.00 (6.42)	0.00 (6.42)	0.00 (6.42)
4.	<i>M. anisopliae</i>	4	0.00 (6.42)	0.00 (6.42)	0.00 (6.42)	0.00 (6.42)	0.00 (6.42)	0.00 (6.42)	0.00 (6.42)	0.00 (6.42)	0.00 (6.42)	0.00 (6.42)
5.	<i>B. bassiana</i>	4	0.00 (6.42)	0.00 (6.42)	0.00 (6.42)	0.00 (6.42)	0.00 (6.42)	0.00 (6.42)	0.00 (6.42)	0.00 (6.42)	0.00 (6.42)	0.00 (6.42)
6.	Dichlorvos 76 EC	2	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)
7.	Clothianidin 50 WDG	0.3	85.00 (67.50)	85.00 (67.50)	87.50 (69.53)	92.50 (76.17)	92.50 (78.05)	100.00 (97.50)	100.00 (97.50)	100.00 (97.50)	100.00 (90.00)	100.00 (90.00)
8.	Buprofezin 25 SC	2.5	0.00 (6.42)	0.00 (6.42)	0.00 (6.42)	0.00 (6.42)	0.00 (6.42)	0.00 (6.42)	0.00 (6.42)	0.00 (6.42)	0.00 (6.42)	0.00 (6.42)
9.	Profenophos 50 EC	3	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)
10.	Imidacloprid 17.8 SL	0.4	82.50 (65.84)	82.50 (65.84)	70.00 (56.95)	87.50 (72.11)	85.00 (70.45)	100.00 (97.50)	100.00 (97.50)	100.00 (97.50)	100.00 (90.00)	100.00 (90.00)
11.	Thiamethoxam 25 WG	0.4	85.00 (70.45)	85.00 (70.45)	82.50 (65.84)	92.50 (76.17)	100.00 (97.50)	100.00 (97.50)	100.00 (97.50)	100.00 (97.50)	100.00 (90.00)	100.00 (90.00)
12.	Triazophos 40 EC	1.25	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)
13.	Chlorpyrifos 20 EC	3	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)	100.00 (90.00)
14.	Untreated		0.00 (6.42)	0.00 (6.42)	0.00 (6.42)	0.00 (6.42)	0.00 (6.42)	0.00 (6.42)	0.00 (6.42)	0.00 (6.42)	0.00 (6.42)	0.00 (6.42)
	S.E. $\pm$		3.01	3.02	2.02	3.18	2.89	0.78	1.75	2.95	0.00	0.00
	C.D. at 5 %		8.58	8.62	5.76	9.07	8.24	2.24	5.00	8.41	0.00	0.00

*Figures in parentheses are Arc sine transformed values

The low mortality of *A. bambawalei* was found in females than in males because females were larger in size which enabled them to endure the toxicity of insecticides for longer times. The direct exposure of dichlorvos, profenophos, triazophos and chlorpyriphos caused 100 per cent mortality within 1 h because chances of picking up a lethal dose were much higher in closed environment than under field condition where chances of parasitoid moving away from the treated area were more.

4.7 Evaluation of different insecticides for the management of cotton mealybug *P. solenopsis*

The field experiment was conducted on *Bt* cotton to evaluate the efficacy of different biopesticides and insecticides during *Kharif*, 2008 and *Kharif*, 2009 and presented in Table 12, 13, 14 and 15. Thirteen biopesticides and insecticides *viz.*, neem oil 0.03 %, NSKE 5%, *V. lecanii*, *M. anisopliae*, *B. bassiana*, dichlorvos 76 EC, clothianidin 50 WDG, buprofezin 25 SC, profenophos 50 EC, imidacloprid 17.8 SL, thiamethoxam 25 WG, triazophos 40 EC and chlorpyriphos 20 EC were evaluated for management of mealybug infesting cotton. Two sprays of above insecticides were given at an interval of 15 days.

4.7.1 First spray (*Kharif*, 2008)

Before initiation of insecticide spray treatments the pre-count population of the mealybug ranged from 99.43 to 119.58/10 cm apical shoot (Table-12). Difference in the mealybug population among the plots was statistically significant on a day before the treatment.

All insecticidal treatments were significantly superior over untreated control in minimizing the incidence of *P. solenopsis* on cotton. On 3rd days after spray, profenophos 50 EC @1500 ml ha⁻¹ was the most effective treatment (51.65 mealybugs/10 cm) followed by chlorpyriphos 20 EC @ 1500 ml ha⁻¹ (53.71 mealybugs/10 cm) and

both the treatments were at par with each other. Similar trend was observed on seventh and tenth day after first spray. Next effective treatment was dichlorvos 76 EC @ 1000 ml ha⁻¹ (57.28 mealybugs/10 cm) followed by triazophos 40 EC @ 625 ml ha⁻¹ (59.07 mealybugs) which were at par with each other. Similar trend was observed seven and ten days after spray. Next significant treatments were imidacloprid 17.8 SL (67.11 mealybugs/10 cm) followed by clothianidin 50 WDG (69.30 mealybugs) and were at par with each other (Table-12).

Ten days after spray, mealybug population slightly increased in imidacloprid 17.8 SL and clothianidin 50 WDG, which recorded 39.15 and 42.15 mealybugs/10 cm, respectively. The mealybug population was slightly increased in NSKE 5 % and neem oil 0.03% and these treatments recorded 71.05 and 78.45 mealybugs/10 cm, respectively. Among biopesticides, *V. lecanii* @ 2000 g ha⁻¹ was found promising and recorded 61.60 mealybugs/10 cm.

Fourteen days after spray, the treatment with buprofezin 25 SC @ 1250 ml ha⁻¹ recorded significantly lowest mealybug population of 24.30 mealybugs /10 cm and population was found significantly superior over rest of the treatments. Among biopesticides *V. lecanii* @ 2000 g ha⁻¹ was promising and recorded 54.05 mealybugs /10 cm followed by *M.anisopliae* and *B.bassiana* which recorded 63.00 and 68.35 mealybugs/10 cm, respectively. The rest of the treatments recorded increased mealybug population and was maximum in neem oil (85.78 mealybugs/10 cm). Untreated control recorded highest population of 130.35 mealybugs/10 cm. Mealybug population on untreated plants (control) showed an increasing trend from 117.73 to 130.35 mealybugs/10 cm apical shoot during a span of 14 days after the first spray (Fig.4).

Table 12. Efficacy of different treatments against mealybug during *Kharif*, 2008 (First spray)

Sr. No.	Treatments	Dosage (ml or g/ ha)	Survival population of mealybug/ 10 cm apical shoot				
			Precount	3 DAS	7 DAS	10 DAS	14 DAS
1	Neem oil 0.03% EC	2000	104.35 (10.26)*	79.50 (8.97)	68.26 (8.32)	78.45 (8.91)	85.78 (9.32)
2	NSKE 5%	25000	99.43 (10.02)	77.58 (8.86)	65.89 (8.18)	71.05 (8.49)	80.55 (9.03)
3	<i>V. lecanii</i> 1× 10 ⁸ CFU/g	2000	115.08 (10.77)	104.72 (10.28)	76.38 (8.80)	61.60 (7.91)	54.05 (7.42)
4	<i>M. anisopliae</i> 1× 10 ⁸ CFU/g	2000	112.68 (10.66)	106.63 (10.37)	80.73 (9.04)	70.23 (8.44)	63.00 (8.00)
5	<i>B. bassiana</i> 1× 10 ⁸ CFU/g	2000	114.45 (10.74)	108.55 (10.47)	87.05 (9.38)	74.08 (8.66)	68.35 (8.33)
6	Dichlorvos 76 EC	1000	119.58 (10.98)	57.28 (7.63)	29.06 (5.48)	27.18 (5.31)	36.54 (6.13)
7	Clothianidin 50 WDG	150	108.27 (10.45)	69.30 (8.38)	35.52 (6.04)	42.15 (6.57)	49.30 (7.09)
8	Buprofezin 25 SC	1250	105.55 (10.32)	89.20 (9.50)	60.53 (7.84)	30.78 (5.64)	24.30 (5.03)
9	Profenophos 50 EC	1500	112.18 (10.64)	51.65 (7.26)	23.13 (4.91)	20.13 (4.60)	30.45 (5.61)
10	Imidacloprid 17.8 SL	200	118.03 (10.91)	67.11 (8.25)	34.57 (5.96)	39.15 (6.34)	45.68 (6.83)
11	Thiamethoxam 25 WG	200	110.80 (10.57)	72.40 (8.57)	38.97 (6.32)	35.04 (6.00)	42.05 (6.56)
12	Triazophos 40 EC	625	116.86 (10.86)	59.07 (7.75)	30.84 (5.64)	28.86 (5.46)	38.24 (6.26)
13	Chlorpyrifos 20 EC	1500	111.60 (10.61)	53.71 (7.40)	25.01 (5.10)	22.08 (4.80)	32.25 (5.77)
14	Untreated		117.73 (10.90)	121.00 (11.05)	127.78 (11.35)	126.58 (11.29)	130.35 (11.46)
	S.E. ±		0.11	0.13	0.16	0.12	0.20
	C.D. at 5 %		0.33	0.37	0.46	0.35	0.56

DAS-days after spray;

* Figures in the parentheses are $\sqrt{(n+1)}$ transformed values

4.7.2 Second spray (*Kharif*, 2008)

The data in Table 13 revealed that on 3rd and 7th days after second spray, the treatment profenophos 50 EC @ 1500 ml ha⁻¹

was found superior over rest of the treatments by recording the mealybugs population of 16.30 and 9.65 mealybugs/10 cm apical shoot, respectively, except chlorpyrifos 20 EC @ 1500 ml ha⁻¹ (19.35 and 11.95 mealybugs/10 cm, respectively) and both the treatments were at par with each other. Next effective treatment on 3 DAS was buprofezin 25 SC @ 1250 ml ha⁻¹ followed by dichlorvos 76 EC @ 1000 ml ha⁻¹ which was at par with each other and recorded 22.55 and 26.16 mealybugs/10 cm and triazophos 40 EC @ 625 ml ha⁻¹, (28.57 mealybugs/10 cm). On 7 DAS, dichlorvos recorded 15.12 mealybug/10 cm which was at par with triazophos and buprofezin. Next effective treatment was imidacloprid 17.8 SL @ 200 g ha⁻¹ (33.40 and 21.35 mealybugs/10 cm) followed by clothianidin 50 WDG @ 150 g ha⁻¹ (35.38 and 24.81 mealybugs/10 cm) (Table-13).

Ten and fourteen days after spray, population of mealybug slightly increased in dichlorvos 76 EC (19.78 and 24.25 mealybugs), triazophos 40 EC (20.29 and 28.15 mealybugs), imidacloprid 17.8 SL (24.75 and 30.48 mealybugs), clothianidin 50 WDG (26.17 and 33.43 mealybugs), thiamethoxam 25 WG (28.31 and 35.78 mealybugs), NSKE 5 % (62.63 and 69.55) and neem oil (67.75 and 72.33).

Fourteen days after spray, the treatment with buprofezin 25 SC @ 1250 ml ha⁻¹ recorded significantly lowest population (9.45 mealybugs/10 cm). Among biopesticides, *V. lecanii* @ 2000 g ha⁻¹ was promising and recorded 34.93 mealybugs/10 cm followed by *M.anisopliae* and *B.bassiana* which recorded 43.63 and 46.48 mealybugs/10 cm, respectively. The neem oil 3 per cent had maximum population (72.33 mealybugs/10 cm) among all biopesticide treatments. Untreated control recorded highest population of 136.20 mealybugs/10 cm apical shoot.

Profenophos 50 EC @ 1500 ml ha⁻¹ recorded highest cotton yield of 24.60 q ha⁻¹ and it was on par with buprofezin 25 SC @ 1250 ml ha⁻¹, chlorpyrifos 20 EC @ 1500 ml ha⁻¹, dichlorvos 76 EC and triazophos 40 EC. Among treatments minimum yield of 14.00 q ha⁻¹ was recorded neem oil 0.03 EC treatment which was on par with NSKE 5 per cent (14.90 q ha⁻¹), *B.bassiana* and *M. anisopliae*. The untreated check recorded the lowest seed cotton yield of 13.00 q ha⁻¹ during 2008 season (Table 13) (Fig.5).

4.7.3 First spray (*Kharif*, 2009)

Before initiation of insecticide spray treatments the pre-count population of the mealybug ranged from 91.63 to 113.00/10 cm apical shoot (Table-14). Difference in the mealybug population among the plots was statistically significant on a day before the treatment.

Three and seven days after first spray (*Kharif*, 2009), profenophos 50 EC recorded the lowest mealybug population 52.38 and 26.75 mealybugs/10 cm apical shoot, respectively and this treatment was at par with chlorpyrifos 20 EC @ 1500 ml ha⁻¹ where 54.00 and 29.60 mealybugs/10 cm apical shoot were recorded. Next effective treatment was dichlorvos 76 EC @ 1000 ml ha⁻¹ which recorded 59.27 and 34.33 mealybugs after three and seven days after spray followed by triazophos 40 EC @ 625 ml ha⁻¹, 61.83 and 37.04 mealybugs and both the treatments were at par with each other. Next effective treatment was imidacloprid 17.8 SL @ 200 g ha⁻¹ (64.35 and 43.03 mealybugs) followed by clothianidin 50 WDG @ 150 g ha⁻¹ (65.42 and 44.14 mealybugs) and were at par with each other (Table 14).

Table 13. Efficacy of different treatments against mealybug during Kharif, 2008 (second spray)

Sr. No.	Treatments	Dosage (ml or g/ha)	Survival population of mealybugs/10 cm apical shoot				Yield (q/ha)
			3 DAS	7 DAS	10 DAS	14 DAS	
1	Neem oil 0.03% EC	2000	66.88 (8.24)*	60.65 (7.85)	67.75 (8.29)	72.33 (8.56)	14.00
2	NSKE 5%	25000	63.50 (8.03)	58.53 (7.72)	62.63 (7.98)	69.55 (8.40)	14.90
3	<i>V. lecanii</i> 1×10 ⁸ CFU/g	2000	52.73 (7.33)	44.33 (6.73)	40.23 (6.42)	34.93 (5.99)	17.10
4	<i>M. anisopliae</i> 1×10 ⁸ CFU/g	2000	59.61 (7.79)	52.15 (7.29)	48.55 (7.04)	43.63 (6.68)	15.90
5	<i>B. bassiana</i> 1×10 ⁸ CFU/g	2000	64.04 (8.06)	54.43 (7.44)	50.35 (7.17)	46.48 (6.89)	15.20
6	Dichlorvos 76 EC	1000	26.16 (5.21)	15.12 (4.02)	19.78 (4.56)	24.25 (5.02)	22.70
7	Clothianidin 50 WDG	150	35.38 (6.03)	24.81 (5.08)	26.17 (5.21)	33.43 (5.87)	21.00
8	Buprofezin 25 SC	1250	22.55 (4.85)	17.95 (4.35)	13.25 (3.77)	9.45 (3.23)	24.00
9	Profenophos 50 EC	1500	16.30 (4.16)	9.65 (3.26)	7.15 (2.85)	14.20 (3.90)	24.60
10	Imidacloprid 17.8 SL	200	33.40 (5.87)	21.35 (4.73)	24.75 (5.07)	30.48 (5.61)	18.90
11	Thiamethoxam 25 WG	200	36.44 (6.12)	20.76 (4.66)	28.31 (5.41)	35.78 (6.06)	19.60
12	Triazophos 40 EC	625	28.57 (5.44)	16.08 (4.13)	20.29 (4.61)	28.15 (5.40)	21.80
13	Chlorpyrifos 20 EC	1500	19.35 (4.51)	11.95 (3.60)	15.01 (4.00)	20.35 (4.62)	23.30
14	Untreated		132.63 (11.56)	134.10 (11.62)	135.15 (11.67)	136.20 (11.71)	13.00
	S.E. ±		0.21	0.19	0.20	0.18	0.94
	C.D. at 5 %		0.60	0.55	0.58	0.53	2.90

DAS-days after spray;

*Figures in the parentheses are $\sqrt{(n+1)}$ transformed values

Table 14. Efficacy of different treatments against mealybug during Kharif, 2009 (First spray)

Sr. No.	Treatments	Dosage (ml or g/ha)	Survival population of mealybugs/10 cm apical shoot
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		g/ ha)	Precount	3 DAS	7 DAS	10 DAS	14 DAS
1	Neem oil 0.03% EC	2000	102.63 (10.18)*	81.73 (9.10)	65.35 (8.15)	70.90 (8.48)	78.88 (8.94)
2	NSKE 5%	25000	96.64 (9.88)	69.58 (8.40)	62.83 (7.99)	68.78 (8.35)	74.43 (8.68)
3	<i>V. lecanii</i> 1× 10 ⁸ CFU/gm	2000	94.11 (9.75)	82.61 (9.14)	57.83 (7.67)	54.70 (7.46)	50.08 (7.15)
4	<i>M. anisopliae</i> 1× 10 ⁸ CFU/gm	2000	95.45 (9.82)	84.33 (9.24)	68.10 (8.31)	63.83 (8.05)	58.15 (7.69)
5	<i>B. bassiana</i> 1× 10 ⁸ CFU/gm	2000	91.63 (9.62)	85.15 (9.28)	70.80 (8.47)	67.18 (8.26)	60.63 (7.85)
6	Dichlorvos 76 EC	1000	103.30 (10.21)	59.27 (7.76)	34.33 (5.94)	30.73 (5.63)	36.06 (6.09)
7	Clothianidin 50 WDG	150	97.35 (9.92)	65.42 (8.15)	44.14 (6.72)	41.45 (6.52)	45.73 (6.84)
8	Buprofezin 25 SC	1250	100.41 (10.07)	82.85 (9.16)	57.38 (7.64)	34.90 (5.99)	24.25 (5.02)
9	Profenophos 50 EC	1500	105.80 (10.33)	52.38 (7.31)	26.75 (5.27)	21.80 (4.77)	32.85 (5.82)
10	Imidacloprid 17.8 SL	200	98.29 (9.96)	64.35 (8.08)	43.03 (6.64)	39.35 (6.35)	45.63 (6.83)
11	Thiamethoxam 25 WG	200	98.70 (9.98)	66.31 (8.20)	44.93 (6.78)	38.78 (6.31)	48.14 (7.01)
12	Triazophos 40 EC	625	99.77 (10.04)	61.83 (7.93)	37.04 (6.17)	32.90 (5.82)	38.65 (6.30)
13	Chlorpyrifos 20 EC	1500	108.03 (10.44)	54.00 (7.42)	29.60 (5.53)	27.43 (5.33)	33.10 (5.84)
14	Untreated		113.00 (10.68)	110.58 (10.56)	101.71 (10.13)	102.03 (10.15)	100.28 (10.06)
	S.E. $\pm$		0.12	0.14	0.19	0.19	0.17
	C.D. at 5 %		0.36	0.40	0.53	0.55	0.48

DAS-days after spray;

*Figures in the parentheses are $\sqrt{(n+1)}$ transformed values

Ten and fourteen days after spray, population of mealybug was slightly increased in imidacloprid 17.8 SL (39.35 and 45.63 mealybugs/10 cm), clothianidin 50 WDG (41.45 and 45.73 mealybugs/10 cm), NSKE 5 % (68.78 and 74.43 mealybugs/10 cm) and neem oil (70.90 and 78.88 mealybugs/10 cm), respectively.

On 14th day after spray, lowest mealybugs population of 24.25 was recorded in buprofezin 25 SC @ 1250 ml ha⁻¹ and this

treatment was significantly superior over rest of the treatments. Among biopesticides, *V. lecanii* @ 2000 g ha⁻¹ was promising and recorded 50.08 mealybugs/10 cm followed by *M.anisopliae* and *B.bassiana* which recorded 58.15 and 60.63 mealybugs/10 cm, respectively. The maximum population was noticed in neem oil (78.88 mealybugs/10 cm). Untreated control recorded highest population of 100.28 mealybugs/10 cm apical shoot (Fig.6).

4.7.4 Second spray (Kharif, 2009)

Three and seven days after second spray, profenophos 50 EC @ 1500 ml ha⁻¹ was found to be superior over rest of the treatments by reducing the mealybugs population to 15.20 and 8.48 mealybugs/10 cm apical shoot, respectively, followed by chlorpyriphos 20 EC @ 1500 ml ha⁻¹ ,18.03 and 10.83 mealybugs and both the treatments were at par with each other. Next effective treatment was dichlorvos 76 EC @ 1000 ml ha⁻¹ which recorded 20.76 and 13.06 mealybugs followed by triazophos 40 EC @ 625 ml ha⁻¹ was noted 22.68 and 13.60 mealybugs/10 cm respectively and both the treatments were at par with each other. The other effective treatments were imidacloprid 17.8 SL @ 200 g ha⁻¹ (26.60 and 18.13 mealybugs/10 cm) and clothianidin 50 WDG @ 150 g ha⁻¹ (27.51 and 19.80 mealybugs/10 cm) and both the treatments were at par with each other (Table-15).

Ten and fourteen days after spray, population of mealybug was slightly increased in dichlorvos 76 EC (14.23 and 18.05 mealybugs/10 cm), triazophos 40 EC (16.40 and 17.73 mealybugs/10 cm), imidacloprid 17.8 SL (21.61 and 20.85 mealybugs/10 cm), clothianidin 50 WDG (23.28 and 23.90 mealybugs/10 cm), thiamethoxam 25 WG (25.33 and 28.60 mealybugs/10 cm) and neem oil (45.90 and 50.83 mealybugs/10 cm).

Fourteen days after spray, the treatment with buprofezin 25 SC @ 1250 ml ha⁻¹ recorded significantly lowest population (7.63 mealybugs/10 cm) and was found significantly superior over rest of the treatments. Among biopesticides *V. lecanii* @2000 g ha⁻¹ was promising and recorded 28.05 mealybugs/10 cm followed by *M. anisopliae* and *B. bassiana* which recorded 35.49 and 38.55 mealybugs/10 cm, respectively. The neem oil had maximum population (50.83 mealybugs/10 cm) among all treatments. Untreated control recorded highest population of 110.08 mealybugs/10 cm apical shoot (Fig. 7).

During 2009 season profenophos 50 EC @ 1500 ml ha⁻¹ recorded highest seed cotton yield of 23.90 q ha⁻¹. It was on par with buprofezin 25 SC @ 1250 ml ha⁻¹ which recorded seed cotton yield of 23.71 q ha⁻¹ and both the treatments were significantly superior over rest of the treatments. Minimum seed cotton yield of 13.20 q ha⁻¹ was recorded in neem oil 0.03 per cent treatment which was significantly superior over control which recorded lowest seed cotton yield of 12.10 q ha⁻¹ (Table-15) (Fig.9).

Table 15. Efficacy of different treatments against mealybug during Kharif, 2009 (second spray)

Sr. No.	Treatments	Dosage (ml or g/ha)	Survival population of mealybugs / 10 cm apical shoot				Yield (q/ha)
			3 DAS	7 DAS	10 DAS	14 DAS	
1	Neem oil 0.03% EC	2000	63.20 (8.01)*	45.20 (6.80)	45.90 (6.85)	50.83 (7.20)	13.20
2	NSKE 5%	25000	59.85 (7.80)	44.05 (6.71)	40.53 (6.44)	47.78 (6.98)	14.40
3	<i>V. lecanii</i> 1× 10 ⁸ CFU/g	2000	49.23 (7.09)	36.60 (6.13)	31.98 (5.74)	28.05 (5.39)	17.50
4	<i>M. anisopliae</i> 1× 10 ⁸ CFU/g	2000	52.88 (7.34)	42.45 (6.63)	39.15 (6.34)	35.49 (6.04)	16.10

5	<i>B. bassiana</i> 1× 10 ⁸ CFU/g	2000	54.13 (7.42)	44.15 (6.72)	41.90 (6.55)	38.55 (6.29)	14.90
6	Dichlorvos 76 EC	1000	20.76 (4.66)	13.06 (3.75)	14.23 (3.90)	18.05 (4.36)	23.10
7	Clothianidin 50 WDG	150	27.51 (5.34)	19.80 (4.56)	23.28 (4.93)	23.90 (4.99)	20.50
8	Buprofezin 25 SC	1250	23.40 (4.94)	15.13 (4.02)	9.76 (3.28)	7.63 (2.94)	23.71
9	Profenophos 50 EC	1500	15.20 (4.02)	8.48 (3.08)	6.88 (2.81)	12.33 (3.65)	23.90
10	Imidacloprid 17.8 SL	200	26.60 (5.25)	18.13 (4.37)	21.61 (4.75)	20.85 (4.67)	18.20
11	Thiamethoxam 25 WG	200	30.37 (5.60)	17.92 (4.35)	25.33 (5.13)	28.60 (5.44)	19.80
12	Triazophos 40 EC	625	22.68 (4.87)	13.60 (3.82)	16.40 (4.17)	17.73 (4.33)	22.00
13	Chlorpyrifos 20 EC	1500	18.03 (4.36)	10.83 (3.44)	9.83 (3.29)	13.28 (3.78)	23.10
14	Untreated		97.82 (9.94)	101.40 (10.12)	105.63 (10.33)	110.08 (10.54)	12.10
	S.E. +		0.20	0.19	0.18	0.20	0.22
	C.D. at 5 %		0.58	0.54	0.52	0.58	0.67

DAS-days after spray;

*Figures in the parentheses are $\sqrt{(n+1)}$ transformed values

4.7.5 Efficacy of insecticides against mealybug

Pooled data: (Kharif, 2008 and 2009)

The precount population of the mealybug was ranged from 98.03 to 115.36 per 10 cm apical shoot; differences in the mealybug population among the treatments were not statistically significant on a day before the treatment (Table-16).

Three, seven and ten days after spray, profenophos 50 EC @ 1500 ml ha⁻¹ recorded lowest mealybug population of 33.88, 17.00 and 13.99 mealybugs/ 10 cm apical shoot, respectively, which was followed by chlorpyrifos 20 EC@ 1500 ml ha⁻¹, 36.27, 19.35 and 18.58 mealybugs/ 10 cm, respectively. The next effective treatment was dichlorvos 76 EC @ 1000 ml ha⁻¹ which recorded 40.86 and 22.89

mealybugs/ 10 cm followed by triazophos 40 EC @ 625 ml ha⁻¹, 43.03 and 24.39 mealybugs/ 10 cm, three and seven days after spray, respectively. Both these treatments were at par with each other. Next promising treatments were imidacloprid 17.8 SL @ 200 g ha⁻¹ (47.86 and 29.27 mealybugs/ 10 cm) and clothianidin 50 WDG @ 150 g ha⁻¹ (49.40 and 31.07 mealybugs/ 10 cm) at three and seven days after spray, respectively.

Ten and fourteen days after spray, population of mealybug was slightly increased in dichlorvos 76 EC (22.98 and 28.73 mealybugs/ 10 cm), triazophos 40 EC (24.61 and 30.69 mealybugs), imidacloprid 17.8 SL (31.21 and 35.66 mealybugs/ 10 cm), clothianidin 50 WDG (33.26 and 38.09 mealybugs/ 10 cm), thiamethoxam 25 WG (31.86 and 38.64 mealybugs/ 10 cm), NSKE 5 per cent (60.74 and 68.08 mealybugs/ 10 cm) and neem oil (65.75 and 71.95 mealybugs/ 10 cm.) Buprofezin 25 SC @ 1250 ml ha⁻¹ had recorded significantly the lowest population of 16.41 mealybugs/10 cm apical shoot at 14 DAS (Fig.9).

Table 16. Efficacy of different treatments against mealybug
(Pooled data: *Kharif, 2008* and *Kharif, 2009*)

Sr. No.	Treatments	Dosage (ml or g/ ha)	Survival population of mealybugs/10 cm apical shoot at					Yield (q/ha)
			Pre-count	3 DAS	7 DAS	10 DAS	14 DAS	
1	Neem oil 0.03% EC	2000	103.49 (10.22)*	72.83 (8.59)	59.86 (7.80)	65.75 (8.17)	71.95 (8.54)	13.60
2	NSKE 5%	25000	98.03 (9.95)	67.63 (8.28)	57.82 (7.67)	60.74 (7.86)	68.08 (8.31)	14.65
3	<i>V. lecanii</i> 1× 10 ⁸ CFU/g	2000	104.59 (10.28)	72.32 (8.56)	53.78 (7.40)	47.13 (6.94)	41.78 (6.54)	17.30
4	<i>M. anisopliae</i> 1× 10 ⁸	2000	104.06 (10.25)	75.86 (8.77)	60.98 (7.87)	55.44 (7.51)	50.07 (7.15)	16.00

	CFU/g							
5	<i>B. bassiana</i> 1× 10 ⁸ CFU/g	2000	103.04 (10.20)	77.97 (8.89)	64.11 (8.07)	58.38 (7.71)	53.50 (7.38)	15.05
6	Dichlorvos 76 EC	1000	111.44 (10.60)	40.86 (6.47)	22.89 (4.89)	22.98 (4.90)	28.73 (5.45)	22.90
7	Clothianidin 50 WDG	150	102.81 (10.19)	49.40 (7.10)	31.07 (5.66)	33.26 (5.85)	38.09 (6.25)	20.75
8	Buprofezin 25 SC	1250	102.98 (10.20)	54.50 (7.45)	37.75 (6.22)	22.17 (4.81)	16.41 (4.17)	23.86
9	Profenophos 50 EC	1500	108.99 (10.49)	33.88 (5.91)	17.00 (4.24)	13.99 (3.87)	22.46 (4.84)	24.25
10	Imidacloprid 17.8 SL	200	108.16 (10.45)	47.86 (6.99)	29.27 (5.50)	31.21 (5.68)	35.66 (6.05)	18.55
11	Thiamethoxa m 25 WG	200	104.75 (10.28)	51.38 (7.24)	30.64 (5.63)	31.86 (5.73)	38.64 (6.30)	19.70
12	Triazophos 40 EC	625	108.31 (10.46)	43.03 (6.64)	24.39 (5.04)	24.61 (5.06)	30.69 (5.63)	21.90
13	Chlorpyripho s 20 EC	1500	109.81 (10.53)	36.27 (6.11)	19.35 (4.51)	18.58 (4.43)	24.75 (5.07)	23.20
14	Untreated		115.36 (10.79)	115.5 1 (10.79)	116.25 (10.83)	117.34 (10.88)	119.23 (10.96)	12.55
	S.E. ±		0.08	0.07	0.09	0.08	0.10	0.47
	C.D. at 5 %		0.22	0.20	0.25	0.23	0.28	1.45

DAS-days after spray;

*Figures in the parentheses are $\sqrt{(n+1)}$ transformed values

The population was slightly increased in profenophos 50 EC @ 1500 ml ha⁻¹ which treatment was 22.46 mealybugs/ 10 cm and it was at par with chlorpyriphos 20 [EC @ 1500 ml ha⁻¹ 24.75](#) mealybugs/ 10 cm followed by dichlorvos 76 EC @1000 ml ha⁻¹ 28.73 mealybugs/ 10 cm. Mealybug population was increased in all other treatments and population was maximum in neem oil (71.95

mealybugs/ 10 cm). Untreated control recorded highest population of 119.23 mealybugs/10 cm apical shoot.

Considering two years efficacy data the treatment with profenophos 50 EC was found the most effective treatment followed by buprofezin 25 SC, chlorpyriphos 20 EC, dichlorvos 76 EC and triazophos 40 EC. Among biopesticides *V. lecanii* was most effective

4.8 Economics of different treatments (Kharif, 2008 and 2009)

During *Kharif*, 2008 a maximum gross income of Rs. 73,800 per ha was recorded in profenophos 50 EC @ 1500 ml ha⁻¹ followed by buprofezin 25 SC @ 1250 ml ha⁻¹ which recorded Rs. 72,000 per ha. However, the highest net return of Rs 71,760 per ha was noticed in profenophos 50 EC @ 1500 ml ha⁻¹ followed by chlorpyriphos @ 1500 ml ha⁻¹ which yielded Rs. 68,550 with the ICBR ratio of 1:17.53 and 1:24.11, respectively (Table-17).

However, in *Kharif*, 2009 a maximum gross income of Rs. 95,600 per ha was obtained in profenophos 50 EC @ 1500 ml ha⁻¹ followed by buprofezin 25 SC @ 1250 ml ha⁻¹ which recorded Rs. 94,840. Similarly, the highest net return of Rs. 93,200 per ha was recorded in profenophos 50 EC @ 1500 ml ha⁻¹ followed by buprofezin 25 SC @ 1250 ml ha⁻¹ , Rs. 90,815 with the ICBR ratio of 1:18.17 and 1:10.54, respectively (Table-18).

In pooled data of both the seasons profenophos 50 EC @ 1500 ml ha⁻¹ recorded significantly highest seed cotton yield of 24.25 qt ha⁻¹. It was on par with buprofezin 25 SC @ 1250 ml ha⁻¹ which recorded seed cotton yield of 23.86 qt ha⁻¹, chlorpyriphos 20 EC and dichlorvos 76 EC. Minimum seed cotton yield of 13.60 qt ha⁻¹ was recorded in neem oil 0.03 per cent which was significantly

superior over control which recorded lowest seed cotton yield of 12.55 qt ha⁻¹ (Table 16) (Fig. 9).

The economic analysis of the usage of chemicals is required to judge the effective and economic insecticide among the tested treatments. In the present study economic analysis revealed that profenophos, buprofezin and chlorpyriphos were found to be effective for the management of mealybugs on cotton. Profenophos 50 EC, buprofezin 25 SC and chlorpyriphos 20 EC recorded maximum net gain of Rs. 35,760 ha⁻¹, Rs. 32,272 ha⁻¹ and Rs. 32,550 ha⁻¹, respectively compared to untreated control during *Kharif*, 2008, while during *Kharif*, 2009 profenophos, chlorpyriphos and buprofezin obtained the net gain over control of Rs. 43,600/- , Rs. 42,415/-and Rs. 42,410/- respectively.

Table 17. Economics of different treatments (2008)

Sr. No.	Treatment	Formulation	Dose (ml or g /ha)	Yield (q/ha)	Incremental yield over control	Total Cost of insecticide (Rs/ha)	Total treatment Cost (Rs/ha)	Gross Return (Rs/ha)	Net return (Rs/ha)	Net Gain over control	ICBR Ratio
1	Neem oil	0.03 % EC	2000	14.00	1.00	1156	1876	4200	40124	4124	1:2.20
2	NSKE	5%	2500	14.90	1.90	500	1220	4470	43480	7480	1:6.13
3	<i>V. lecanii</i>	1 × 10 ⁸ CFU/g	2000	17.10	4.10	500	1220	5130	50080	14080	1:11.5
4	<i>M. anisopliae</i>	1 × 10 ⁸ CFU/g	2000	15.90	2.90	500	1220	4770	46480	10480	1:8.59
5	<i>B. bassiana</i>	1 × 10 ⁸ CFU/g	2000	15.20	2.20	500	1220	4560	44380	8380	1:6.87
6	Dichlorvos	76 EC	1000	22.70	9.70	904	1624	6810	66476	30476	1:18.7
7	Clothianidin	50 WDG	150	21.00	8.00	3450	4170	6300	58830	22830	1:5.47
8	Buprofezin	25 SC	1250	24.60	11.00	3008	3728	7200	68272	32272	1:8.66
9	Profenophos	50 EC	1500	24.00	11.60	1320	2040	7380	71760	35760	1:17.5
10	Imidacloprid	17.8 SL	200	18.90	5.90	2400	3120	5670	53580	17580	1:5.63
11	Thiamethoxa	25 WG	200	19.60	6.60	1300	2020	5880	56780	20780	1:10.2
12	Triazophos	40 EC	625	21.80	8.80	537	1257	6540	64143	28143	1:22.3
13	Chlorpyrifos	20 EC	1500	23.30	10.30	630	1350	6990	68550	32550	1:24.1
14	Untreated	--	--	13.00	0.00	0	0	3600	36000	0	---

- Cotton price -Rs. 3000/qt
- *Verticillium lecanii*- Rs.125/kg
- Dichlorvos Rs.452/lit
- Profenophos 50 EC- Rs. 440/lit
- Triazophos 40 EC-Rs.430/lit
- Neem oil 0.03 %-Rs 289/lit
- *Metarhizium anisopliae* Rs. - 125/kg
- Clothianidin 50 WDG- Rs.1150/100 g
- Imidacloprid-17.8 SL-Rs.6000/lit
- Chlorpyrifos 20 EC-Rs.210/lit
- NSK-Rs. 10 /kg
- *Beauveria bassiana* Rs - 125/kg
- Buprofezin 25 SC - Rs.1203/ lit
- Thiamethoxam 25 WG-Rs. 325/100 g
- Labour cost for one spray- Rs. 360/ha/spray @ Rs.120/ labour /day

Net gain over control= Gross return (Rs./ha) - Total treatment cost (Rs./ha) - Yield of untreated plot (Rs./ha)

Table 18. Economics of different treatments (2009)

Sr. No.	Treatment	Formulation	Dose (ml/g /ha)	Yield (q/ ha)	Incremental yield over control	Total cost of insecticide used (Rs/ha)	Total treatment cost (Rs. /ha)	Gross Return (Rs/ha)	Net return (Rs/ ha)	Net gain over control	ICBR Ratio
1	Neem oil	0.03 % EC	2000	13.20	1.10	1156	2056	5280	5074	2344	1:1.14
2	NSKE	5%	2500	14.40	2.30	600	1500	5760	5610	7700	1:5.13
3	<i>V.lecanii</i>	1× 10 ⁸	2000	17.50	5.40	500	1400	7000	6860	2020	1:14.43
4	<i>M.anisopliae</i>	1× 10 ⁸	2000	16.10	4.00	500	1400	6440	6300	1460	1:10.43
5	<i>B.bassiana</i>	1× 10 ⁸	2000	14.90	2.80	500	1400	5960	5820	9800	1:7.00
6	Dichlorvos	76 EC	1000	23.10	11.00	1080	1980	9240	9042	4202	1:21.22
7	Clothianidin	50 WDG	150	20.50	8.40	3600	4500	8200	7750	2910	1:6.47
8	Buprofezin	25 SC	1250	23.71	11.61	3125	4025	9484	9081	4241	1:10.54
9	Profenophos	50 EC	1500	23.90	11.80	1500	2400	9560	9320	4360	1:18.17
10	Imidacloprid	17.8 SL	200	18.20	6.10	2560	3460	7280	6934	2094	1:6.05
11	Thiamethoxa	25 WG	200	19.80	7.70	1400	2300	7920	7690	2850	1:12.39
12	Triazophos	40 EC	625	22.00	9.90	563	1463	8800	8653	3813	1:26.07
13	Chlorpyrifos	20 EC	1500	23.10	11.00	690	1590	9240	9081	4241	1:26.67
14	Untreated	--	--	12.10	0.00	0	0	4840	4840	0	--

- Cotton price -Rs. 4000/qt ➤ Neem oil 0.03 %-Rs 289/lit ➤ NSK-Rs. 12 /kg
- *Verticillium lecanii*- Rs.125/kg ➤ *Metarhizium anisopliae* Rs. - 125/kg ➤ *Beauveria bassiana* Rs - 125/kg
- Dichlorvos Rs.540/lit ➤ Clothianidin 50 WDG- Rs.1200/100 g ➤ Buprofezin 25 SC - Rs.1250/ lit
- Profenophos 50 EC- Rs. 500/lit ➤ Imidacloprid-17.8 SL-Rs.6400/lit ➤ Thiamethoxam 25 WG-Rs. 350/100 g
- Triazophos 40 EC-Rs.540/lit ➤ Chlorpyrifos 20 EC-Rs.230/lit ➤ Labour cost for one spray- Rs. 450/ha/spray @ Rs.120/ labour /day

Net gain over control= Gross return (Rs./ha) - Total treatment cost (Rs./ha) - Yield of untreated plot (Rs./ha)

5. DISCUSSION

The results obtained from different experiments on the cotton mealybug as envisaged in the introductory chapter are discussed hereunder.

5.1 Biology of *P.solenopsis*

5.1.1 Morphometrics of different life stages of *P.solenopsis* under laboratory conditions

The observations made on the biology of *P. solenopsis* reared in the laboratory are discussed below. In the present study, the eggs were oblong in shape and pale yellow in colour. Similar observations with respect of egg colour and shape were recorded by Dhawan and Saini (2009). However, Aheer *et al.* (2009) reported that the eggs of *P.solenopsis* were orange in colour and elongate in shape. It was observed that the eggs were laid in ovisacs. Production of ovisacs by *P. solenopsis* female for depositing eggs has earlier been reported by different researchers (McKenzie, 1967; Saini and Ram, 2008; Aheer *et al.*, 2009; Dhawan and Saini, 2009). The eggs of *P. solenopsis* measured 0.45 ± 0.02 and 0.21 ± 0.02 mm in length and width, respectively. Similarly, egg size has been reported as 0.45×0.20 mm (Aheer *et al.*, 2009), 0.37×0.17 mm (Dhawan and Saini, 2009) and 0.37×0.19 mm (Patel *et al.*, 2010).

The first instar nymphs were oblong in shape, pale yellow or creamish yellow in colour. Almost similar description has been given by other workers (Akintola and Ande, 2008; Aheer *et al.*, 2009; Dhawan and Saini, 2009, Patel *et al.* 2010). First instar nymph measured 0.61 ± 0.04 mm in length and 0.29 ± 0.02 mm in width. However, different scientists have observed variable size of first instar nymphs. Nymphal size has been reported as

0.71 to 0.73 x 0.35 to 0.38 mm (Hodgson *et al.*, 2008), 0.5 x 0.25 mm (Aheer *et al.*, 2009), 0.73 x 0.47 mm (Dhawan and Saini, 2009) and 0.41 x 0.20 mm (Patel *et al.*, 2010)

The second instar nymphs were oblong in shape, creamish in colour. Akintola and Ande (2008), Dhawan and Saini (2009) and Patel *et al.* (2010) also observed similar colour and shape of second instar nymphs. Whereas, Hodgson *et al.* (2008) observed second instars to be oval in shape, while, Aheer *et al.* (2009) reported that second instar was light green in colour which was different from the present findings. In the present study second instar nymphs were measured 1.30 ± 0.17 mm in length and 0.63 ± 0.08 mm in width. These measurements were in conformity with the observations made by different scientists (Hodgson *et al.*, 2008; Aheer *et al.*, 2009; Dhawan and Saini, 2009; Patel *et al.*, 2010)

Freshly emerged third instar nymphs were oblong in shape and creamish in colour. These measurements agreed with the observations made by Akintola and Ande (2008), Dhawan and Saini (2009) and Patel *et al.* (2010). Two black spots on thoracic region and two black stripes on abdomen were observed. Further, after 24 hours of moulting of second instar, white wax on the dorsal side and white waxy filaments on lateral sides became prominent. Similarly, Dhawan and Saini (2009) also observed darker stripes and wax coating over the third instar nymphs. Third instar nymph measured 2.13 ± 0.06 mm long and 1.74 ± 0.02 mm wide. Similar findings were made by other research workers (Hodgson *et al.*, 2008, Aheer *et al.*, 2009; Dhawan and Saini, 2009; Patel *et al.*, 2010).

The pupal stage in mealybug was present in males only. Before pupation, the full grown second instar nymph secreted a silky white cocoon around its body and pupated inside

it. Similar observations were recorded by Aheer *et al.* (2009). However, Patel *et al.* (2010) stated that male formed cocoon after their third moult. The cocoon of mealybug was measured 1.85 ± 0.03 mm in length and 0.54 ± 0.03 mm in width. The present findings are in agreement with the observations of Hodgson *et al.* (2008), Aheer *et al.* (2009) Dhawan and Saini (2009), Patel *et al.* (2010).

The adult female was wingless and its body was oval to oblong in shape with two black spots on thorax and two black stripes on abdomen and covered with white waxy secretion. Similar observations of female shape and colour has been described by different workers (Akintola and Ande, 2008; Dhawan and Saini, 2009, Patel *et al.*, 2010). While, Aheer *et al.* (2009) reported that adult females were light green to pinkish brown in colour. The caudal filaments were present in all the nymphal instars and in adult female. Apart from caudal pair of filament, the adult female developed 18 pairs of lateral white waxy filament. Similarly McKenzie (1967) and Dhawan and Saini (2009) have also reported 18 pairs of such filaments. The adult female measured 3.90 ± 0.06 and 2.05 ± 0.04 mm in length and width, respectively. Different research workers also observed similar body length and width of *P. solenopsis* adult female (McKenzie, 1967, Hodgson *et al.*, 2008, Aheer *et al.*, 2009, Dhawan and Saini, 2009 and Patel *et al.*, 2010).

The adult males were slender, delicate, smoky brown in colour and elongate in shape with a single pair of well developed milky white mesothoracic wings and three pairs of well developed legs. As compared to one pair of caudal filaments in female, the male possessed two pairs of such filaments. The inner pair was considerably longer than other filaments. Hodgson *et al.* (2008) and Aheer *et al.* (2009) also reported the presence of two

pairs of caudal filaments in males. Males measured 1.10 ± 0.06 mm in length and 0.20 ± 0.02 mm width. The present findings are in line with observations of different workers who reported that the size (length $\times$ width) of male was 1.56×0.33 mm (Patel *et al.* 2010), 1.0×0.25 mm (Dhawan and Saini, 2009), 1.0×0.20 mm (Aheer *et al.* 2009) and 1.41 mm in length (Hodgson *et al.* 2008).

5.1.2 Different developmental parameters of *P. solenopsis* on potato sprout under laboratory conditions

The incubation period of *P. solenopsis* eggs was 2.92 ± 1.11 minutes with the range of 1.25 to 5 minutes at 25 ± 2 °C and 65 ± 5 per cent relative humidity. Similar findings on biology were made by Tanwar *et al.* (2007), who reported that reproduction in *P. solenopsis* was mostly parthenogenetic. Eggs were minute, quite smaller and incubation period was of 35 to 45 minutes. (Aheer *et al.* 2009) and 35 to 60 minutes (Patel *et al.* 2010) which is higher than present findings. The female had three nymphal instars, while the male had two nymphal instars along with pupal stage. Duration of first, second and third nymphal instars of female took 4.84 ± 0.75 , 6.22 ± 1.19 and 4.76 ± 0.91 days, respectively. Male mealybug had two nymphal instars. Mean duration of first and second instar was 4.60 ± 0.87 and 7.42 ± 1.55 days, respectively. At the end of second nymphal instar, males produced cocoon (puparia) over their bodies. The pupal period was lasted for 5 to 9 days with mean of 7.20 ± 1.32 days. Pupa was characterized by well developed wing pads attached to mesothorax.

Similar findings on biology of *P. solenopsis* were made by Tanwar *et al.* (2007) who observed that three nymphal instars were in female and two in males which lasted for 13 to 27 days.

Present findings also corroborate with the reports of Mohammad (2008) who reported that *P.solenopsis* life cycle was of 24 to 30 days. Akintola and Ande (2008), documented three nymphal stages which were lasted for six, eight and ten days in female. Similarly, Rishikumar *et al.* (2009) recorded three nymphal stages in female and male (two nymphal instars and a cocoon) in *P. solenopsis*. The total nymphal duration in male and female was 7 to 15 days (mean 12.02 ± 2.42) and 11 to 22 days (mean 15.82 ± 2.85) and longevity was 1 to 3 days (mean 2.08 ± 0.59) and 16 to 26 (mean 21.02 ± 3.02) days, respectively. Similar results were obtained by Aheer *et al.* (2009), who reported three nymphal stages in case of female and two in male with pupal stage. Whereas, Satpute *et al.* (2011) recorded average nymphal duration of 16.8 and 23.5 days of *P.solenopsis* males and females reared on sprouted potatoes, respectively. The longevity of males was 3 to 4 days (mean 3.3) and that of females was 11 to 14 days (mean 12.8).

The pre-oviposition, oviposition and post-oviposition periods of adult female were 3.78 ± 0.69 , 14.28 ± 1.65 and 2.96 ± 0.68 days, respectively. The results were in conformity with the findings made by Dhawan and Saini (2009). However, Patel *et al.* (2010) noted that the pre-oviposition, oviposition and post-oviposition periods of adult female were 8.56, 16.73 and 9.33 days, respectively. These differences may be due to differences in rearing conditions of the insect.

The number of eggs laid by a female of *P. solenopsis* varied greatly with the host on which it was reared. The female formed 4 to 7 ovisacs during its life span from which 312 to 860 crawlers were emerged with a mean of 594.84 ± 64 crawlers when reared on potato sprout. The results were in agreement with the observations made by Patel *et al.* (2010) who reported 400 to 700

eggs per female. However, Dhawan and Saini (2009) also recorded 270 to 340 crawlers emerging from the ovisacs of a single female. While, the number of eggs reported by other scientists was: 386 to 510 eggs in *M. hirsutus* (Mani, 1986) 500 to 600 eggs in *P. solenopsis* (Mohammad 2008), 289 to 517 eggs in *P. solenopsis* (Rishikumar *et. al.*, 2009) and 98 to 239 eggs in *P. solenopsis* on China rose (Aheer *et. al.*, 2009). Variation in the fecundity may be attributed to the difference in climatic conditions in the study period.

As compared to male, longevity of female was 21.02 ± 3.02 days (range 16 to 26) whereas in male the longevity was 2.08 ± 0.59 days (range 1 to 3 days). Similarly, more differences in female and male durations have been reported by Dhawan and Saini (2009) who observed that female lived for 14.8 days while male had an adult duration of 1.6 days only. However, quite high longevity of male (7 to 10 days) and female (32 to 35 days) was reported by Patel *et al.* (2010).

In the present studies, the total life duration of female ranged from 27 to 48 days (mean 36.84 ± 5.87) and male from 13 to 27 days (mean 21.30 ± 4.33). However, other workers have reported differences in total life duration. The total duration was 27 to 38 days in female and 19.5 to 30 days in male (Dhawan and Saini, 2009), 61.5 to 106 days in female and 19.5 to 30 days in male (Aheer *et al.*, 2009) and 55 to 60 days in female and 25 to 30 days in male (Patel *et al.*, 2010). Hundred nymphal mealybugs were observed for sex ratio on sprouted potatoes and 70 per cent were found to be females. The male to female sex ratio was noted to be 1:3 when reared on sprouted potatoes. Similar findings were reported by Satpute *et al.* (2011) who reported 1:3 sex ratio of *P. solenopsis* when maintained on sprouted potatoes.

5.2 Biology of parasitoid, *A. bambawalei*

5.2.1 Morphometrics of different life stages of *A. bambawalei* under laboratory conditions

Life cycle of *A. bambawalei* was studied in the laboratory conditions and it was observed that the egg and larval stages of the parasitoid were not visible due to internal feeding habit but swelling and poor movement of the parasitized mealybug were observed after 3 to 5 days of parasitization. The parasitized mealybugs were transformed into dark brown mummies (cocoon) within 4 to 8 days. This observation is in conformity with Mohamood (2010) and Sangale *et al.* (2013).

Adult emerged out by cutting a circular hole on mummies after pupal period. Antennae were covered with small hair like structures. The apex of antennae was club like with light black colour. Male and females of parasitoid *A. bambawalei* were separated by their morphological characters. Female of parasitoid was bigger than male. Head of male was somewhat dumb-bell shaped, small and attached narrowly with the thorax, whereas in female it was somewhat oval shaped, thorax slightly larger and broadly attached with it. Adults of both the sexes were blackish in colour. The female body was shiny black in colour with large thimble like setigerous punctures on head. In case of male thimble like punctures were more or less similar as in female. Length and width of male was in the range of 1.00 to 1.40 mm and 0.30 to 0.45 mm with an average of 1.20 ± 0.12 mm and 0.39 ± 0.04 mm respectively, whereas in females it ranged from 1.40 to 2.10 mm and 0.65 to 0.85 mm with a mean of 1.81 ± 0.21 mm and 0.78 ± 0.05 mm, respectively. Head width of male ranged from 0.40 to 0.64 mm with a mean of 0.44 ± 0.05 mm, while in females it was 0.70 to 0.90 mm with a mean of 0.84 ± 0.05 mm. The length and width of pupae ranged from 3.20 to 3.45 mm and 1.70 to 1.85 mm with a mean of 3.37 ± 0.06 mm and 1.78 ± 0.05 mm, respectively. Present findings are in accordance with Hayat

(2009) and Vijaya *et al.* (2011). However, Sangale *et al.* (2013) reported that adult male measured 0.79 to 1.27 mm (Av. 1.04 ± 0.04), 0.30 to 0.51 mm (Av. 0.38 ± 0.01) and 0.39 to 0.61 mm (Av. 0.42 ± 0.01) in length, width, and head width, respectively, while female ranged from 1.40 to 1.79 mm (Av. 1.63 ± 0.01) in length, 0.71 to 0.89 mm (Av. 0.80 ± 0.01) in width, 0.78 to 0.96 mm (Av. 0.90 ± 0.01) in head width, respectively. The pupal length and width ranged from 3.43 to 3.53 mm (Av. 3.48 ± 0.01) and 1.75 to 1.94 mm (Av. 1.85 ± 0.02).

5.2.2 Different developmental parameters of *A. bambawalei* under laboratory conditions.

Development of *A. bambawalei* fed on nymphs and adult females of mealybug *P. solenopsis* is discussed below.

A. bambawalei is solitary endoparasitoid and mating took place soon after a day of adult emergence. It completed its life cycle till adulthood in the mealybug body causing mealybug to swell and change its colour to light brown. While, the developing larva at the later stage turned the mealybug in to legless, brown, barrel shaped pupa with dark brown colour. Pupa of parasitoid called mummy was kidney bean shaped. The present findings are in conformity with Tanwar *et al.* (2008) who reported that parasitoid is a solitary endoparasitoid and it caused mealybugs to swell and change their colour to light brown. The developing larva at the later stage turned the mealybug into a legless, brown, barrel-shaped mummy with dark brown in colour.

Larval duration of female and male parasitoid was 5.68 ± 0.99 and 5.86 ± 0.93 days, respectively. However, female and male pupal periods were 7.48 ± 1.23 and 5.44 ± 1.08 days with the range of 6 to 10 and 4 to 7 days, respectively. The development of the male and female parasitoid from the date of parasitization till its emergence from pupa took 10 to 13 and 13 to 18 days with

average of 11.54 ± 1.81 and 15.16 ± 1.57 days, respectively. However, adult male and female longevity was 6.49 ± 1.16 and 15.16 ± 1.57 days with the range from 5 to 8 and 13 to 18 days, respectively. Oviposition and post oviposition period of female was 24.04 ± 4.34 and 3.07 ± 0.96 days with the range from 15 to 31 and 1 to 5 days, respectively. Whereas, adult females parasitized about 25 to 155 with mean of 83.48 ± 34.62 mealybugs in their life. Egg laying capacity per female was estimated on the number of parasitized mealybugs exposed to a pair of the parasitoid in its life and male and female sex ratio in the progeny was 1:2.

The present findings are in agreement with Vijaya *et al.* (2011) and Sangale *et al.* (2013) who recorded that female started egg laying a day after emergence and mean developmental period of male and female parasitoid was 12.08 and 14.08 days, respectively. The mean larval period from parasitization till pupation was 5.80 days for both male and female, while pupal period was 5.95 and 7.04 days, respectively, for male and female. The mean oviposition and post oviposition periods were 24.33 and 3.33 days and mean total fecundity in terms of parasitized hosts was 100.86. Males were short lived (15.86 days) as compared to female (24.90 days).

Similar observation was made by Pala Ram *et al.* (2009) who also observed that mating took place soon after emergence and parasitoid developed in 12 to 14 days. While, female parasitoid parasitized 38 to 163 mealybugs and longevity of female was 11 to 35 days. However, Zain-ul-Abdin *et al.* (2012) found that pupation occurred 8 days after parasitization and 12 to 17 days required for complete development from first day of parasitization till emergence of adult from mummies. The female lived for 15 to 32 days, whereas male died within a week. Female of the parasitoid parasitized 165 mealybugs in its entire life and sex ratio of male to female was recorded as 1:2. Similarly, Solangi

and Mahmood (2010) noted that females lived 10 to 37 days and parasitized 32 to 170 mealybugs and development of parasitoid from the day of parasitization to adult emergence was completed in 11 to 15 days and male to female sex ratio was 1:2.

5.3 Mass production of *P. solenopsis*

5.3.1 Measurement of different life stages of *P. solenopsis* in laboratory conditions

The biological parameters of *P. solenopsis* on three different hosts under laboratory condition were studied and the developmental period of different life stages and other biological parameters as influenced by different hosts are presented below.

Maximum individuals reached to adult in potato sprout were (87.50%) followed by *Hibiscus* (80.83%) and cotton (79.16%). Mealybugs reared on potato sprouts had highest percentage of individuals reaching to adult stage and minimum development time. The developmental period of the first, second, and third nymphal instars of female fed on cotton was 4.60 ± 0.74 (3 to 5.5 days), 6.18 ± 1.07 (4 to 7 days) and 6.00 ± 1.81 (4 to 9 days), respectively. However, on *Hibiscus* it was found to be 5.08 ± 0.59 (3 to 6 days), 6.34 ± 1.09 (4 to 8 days) and 6.24 ± 1.94 (4.5 to 10 days), respectively, whereas, on sprouted potatoes, it was 4.84 ± 0.75 (3 to 6 days), 6.14 ± 1.06 (4 to 7 days) and 4.84 ± 1.22 (4 to 9 days), respectively. Total nymphal period on cotton, *Hibiscus* and potato were 16.78 ± 2.65 , 17.66 ± 2.41 and 15.82 ± 2.66 days, respectively.

The results of present findings are in conformity with Vennila *et.al* (2010) who reported that third nymphal instar was shorter than second. However, Satpute *et al.* (2011) found that 1st, 2nd and 3rd instars lasted for 5.4, 7.6, and 9.5 days, respectively on cotton; 6.6, 8.4 and 11 days, respectively on *Hibiscus* and 6.4, 7.6 and 9.5 days, respectively on sprouted potatoes which was contradictory to present findings. This indicated progressive increase in the developmental period of 1st, 2nd and 3rd instars. Similarly, Akintola and Ande (2008) studied nymphal period on *P. solenopsis* reared on *Hibiscus* and found progressive increase in developmental periods (6, 8 and 10 days) for the 1st, 2nd and 3rd instars, respectively.

The average pre-oviposition, oviposition and post-oviposition period were observed to be 5.16 ± 0.75 , 10.44 ± 1.94 and 2.64 ± 0.49 days, respectively on cotton, 4.92 ± 0.76 , 12.40 ± 1.68 and 2.84 ± 0.37 days, respectively on *Hibiscus* and 3.78 ± 0.69 , 14.28 ± 1.65 and 2.96 ± 0.68 days, respectively on sprouted potatoes. The present findings are in agreement with Kedar (2010) who recorded pre-oviposition, oviposition and post-oviposition period of 5.96 ± 0.73 , 10.08 ± 1.12 and 3.00 ± 0.76 days, respectively on cotton and 7.52 ± 1.12 , 14.36 ± 2.53 and 3.72 ± 1.14 days, respectively on potato sprouts. On the other hand, Satpute *et al.* (2011) recorded pre-oviposition, oviposition and post-oviposition period of 3.4, 2.3 and 5.6 days on cotton, 3.2, 2.5 and 6.3 days on *Hibiscus* and 2.8, 3.3 and 6.7 days on sprouted potatoes, respectively. These differences may be due to differences in rearing conditions of the insect.

The parthenogenic type of reproduction by *P. solenopsis* observed in the present study was in agreement with Vennila *et al.* (2010). Whereas, different modes of reproduction were reported by Hodgson *et al.* (2008) who also recorded sexual

reproduction in *P. solenopsis*. Fecundity on cotton varied from 350 to 630 nymphs per female with a mean of 481.6 ± 92.32 ; on *Hibiscus* it was 380 to 720 nymphs per female with a mean of 492.8 ± 110.92 and on sprouted potatoes the fecundity varied from 312 to 860 nymphs with a mean of 594.84 ± 163.65 nymphs per female mealybug. Satpute *et al.* (2011) who recorded lower fecundity i.e. 215 to 275 nymphs per female on cotton, 260 to 350 nymphs per female on *Hibiscus* and 250 to 320 nymphs per female on sprouted potato.

Longevity of an adult female varied with a mean of 18.24 ± 2.18 (range 14 to 22 days), 20.16 ± 2.44 (range 16 to 24 days) and 21.02 ± 2.34 (range 16 to 26 days) days, respectively when fed on cotton, *Hibiscus* and sprouted potatoes. Similarly, the adult male longevity was 1.76 ± 0.77 (range 1 to 3 days), 1.92 ± 0.75 (range 1 to 3 days) and 2.08 ± 0.59 (range 1 to 3) days, respectively when fed on cotton, *Hibiscus* and sprouted potatoes. The results are in conformity with Akintola and Ande (2008), Kedar (2010) and Satpute *et al.* (2011).

Hundred individuals were observed for sex ratio on each host plant and 68 to 75 per cent were found females. The male to female sex ratio was observed 1:3 on cotton, 1:2.2 on *Hibiscus* and 1:3 on sprouted potatoes. The results are in agreement with Satpute *et al.* (2011).

When the different developmental parameters of the individuals of mealybug reared on cotton, *Hibiscus* and potato sprouts were compared, lot of differences with respect of development period and fecundity were observed. The individuals reared on potato sprouts had higher pre-oviposition period, oviposition period and adult female longevity and fecundity as compared with those reared on cotton and *Hibiscus*. It indicated that rearing of *P. solenopsis* was easier on potato sprouts and

multiplication of the pest was faster on it as compared to other two hosts. Gautam *et al.* (2009) also successfully reared *Phenacoccus solani* on potato sprouts in laboratory. Adult females prefer to feed in juicy mid-veins (Lu *et al.*, 2011).

5.3.2 Development of *P. solenopsis* at different temperatures under laboratory conditions

Lab experiments were carried out to study development rates of *P. solenopsis* at different constant temperatures i.e. 25 ± 2 , 27 ± 2 , 30 ± 2 and 32 ± 2 °C. Total nymphal periods of *P. solenopsis* at 25 ± 2 , 27 ± 2 , 30 ± 2 and 32 ± 2 °C were 16.44 ± 2.74 , 16.25 ± 2.29 , 15.75 ± 1.83 and 16.02 ± 2.36 days, respectively. The average pre-oviposition, oviposition and post-oviposition periods were observed to be 5.24 ± 0.66 , 10.96 ± 2.17 and 2.72 ± 0.46 days at 25 ± 2 °C, 4.96 ± 0.61 , 10.24 ± 1.69 and 2.52 ± 0.51 days at 27 ± 2 °C, 4.68 ± 0.69 , 9.72 ± 1.95 and 2.36 ± 0.49 days at 30 ± 2 °C and 4.28 ± 0.94 , 9.20 ± 1.61 and 2.08 ± 0.76 days at 32 ± 2 °C. Maximum average fecundity was recorded 487.60 ± 92.34 crawlers at 25 ± 2 °C, followed by reduction with increasing temperature i.e. 466.40 ± 89.30 crawlers at 27 ± 2 °C, 442 ± 97.38 crawlers at 30 ± 2 °C, and 410.80 ± 87.51 crawlers at 32 ± 2 °C. The female longevity was maximum i.e. 18.92 ± 2.06 days at 25 ± 2 °C, and then decreased with increasing temperature: 17.72 ± 1.72 days at 27 ± 2 °C, 16.76 ± 1.71 days at 30 ± 2 °C and 15.56 ± 1.51 days at 32 ± 2 °C. Similarly average male longevity was higher 2.40 ± 0.58 days at 25 ± 2 °C, and then decreased with increasing temperatures i.e. 2.12 ± 0.60 days at 27 ± 2 °C, 1.92 ± 0.70 days at 30 ± 2 °C and 1.76 ± 0.78 days at 32 ± 2 °C. A higher female biased sex ratio 1:3 occurred at all temperatures except 32 ± 2 °C. More males at extreme temperature i.e. 1:2.3 (32 °C) could be seen as an adoptive response by males (Walton and Pringle, 2005).

The present findings are in agreement with Anonymous (2011) who recorded developmental rates of *P. solenopsis* at different constant temperatures viz. 25, 27, 30 and 32 °C. The total nymphal period was maximum at 25 °C in all instars and found to be less with increase in temperatures (except 32 °C where nymphal period increased by a few days). The mean fecundity was maximum and found to be decreasing with increase in temperature. Adult female longevity was maximum at both 25 and 27°C temperatures. However, in contrast to it, Goldasteh *et.al* (2009) noted that total nymphal period increased with subsequent increase in temperatures i.e. 15.65 ± 0.21 , 17.89 ± 0.49 , 20.06 ± 0.50 and 24.6 ± 0.66 days at 25, 28, 30 and 32 °C, respectively. Whereas, the study of Copland *et al.* (1985) revealed that *P.citri* laid less than 100 eggs above 30 °C, but can lay over 400 at 18 °C. This is somewhat in agreement with present study. Walton and Pringle (2005) reported that the pre-oviposition period of *P.ficus* lasted for 45.87, 36.11, 33.44, 15.97 and 19.90 days at 18, 20, 25, 27 and 30 °C, respectively, these values were higher than data obtained in current study. According to Hameed *et al.* (2012) temperature is one of the most important ecological factors affecting the physiology and behavior of insects. Being ectothermic organisms, the insects are more subjected to change in rate of growth, development, life time, survival, fecundity and different biological aspects with changing temperature.

The present results indicated that 25 °C is the optimum temperature for population buildup of *P. solenopsis* among the tested temperatures. According to Hameed *et al.* (2012) 20 to 25 °C was suitable temperature for the population buildup of cotton mealybug, similarly, Santa Cecilia *et al.* (2011) reported that 25 °C was the most suitable for development of mealybug.

5.4 Mass multiplication techniques of *A. bambawalei*

5.4.1 Preference of *A. bambawalei* to different stages of mealybug, *P.solenopsis*

The result regarding the host stage preference of *A. bambawalei* showed that maximum mean parasitization percentage (91.00%) was recorded on adult mealybug followed by third instar nymph (81.20%), second instar nymph (31.00%) while no parasitization was observed in first instar nymph of mealybug. Parasitoid preferred adults and 3rd instar host for parasitization. Sex ratio of male to female was (3:2) on second instar mealybug, 1:1.5 on third instar and 1:2 on adult mealybug. The present findings are in conformity with Zain-ul-Abdin *et al.* (2012) who recorded maximum percentage of parasitization on adult host stage (92%), while minimum percentage of parasitization was recorded in 2nd instar nymphs (32%) and no parasitization on 1st instar nymph.

Huang *et al.* (2012) evaluated control effects of *A. bambawalei* on 3rd instar nymphs and female adults of *P. solenopsis*, the parasitic functional response of *A. bambawalei* to *P.solenopsis* were determined. The numbers of parasitized hosts were decreased with the increasing densities of *A.bambawalei*. The parasitizing efficiency was 21.13 for 3rd instar nymph and 6.25 for female adults.

However, Fand *et al.* (2011) observed that more female parasitoids were emerged from mealybugs of third instars whereas; second instars produced a significantly higher proportion of males. According to Karamaouna and Copland (2000) parasitism of second instar mealybugs yielded generally males. Different workers also suggested that large size hosts may

generate superior host parasitoid fitness (Charnov *et al.*, 1981; Liu, 1985; Harvey *et al.*, 1994). A similar relation between parasitoid developmental time and age of the host at the time of oviposition has been reported by Bertschy *et al.* (2000) and Colinet *et al.* (2005).

The results indicated that third instar mealybug is the most suitable host stage for mass rearing of *A. bambawalei* and produced more female progeny as compared with other two host instars of mealybug. According to Zain-ul-Abdin *et al.* (2012) 3rd instar host stage is the most suitable and preferred host stage for mass rearing of *A. bambawalei* in biocontrol programmes as it produces more female progeny of best fitness as compared to the other two host stages (1st and 2nd) of mealybugs. Similarly, Fand *et al.* (2011) suggested that 3rd instar mealybug is the most suitable host stage for mass rearing of *A. bambawalei* and produces more female progeny of the best fitness as compared with other two host stages of mealybugs.

5.4.2 Development of *A. bambawalei* at different temperatures under laboratory condition

Lab experiments were carried out to study the development rates of *A. bambawalei* at different constant temperatures i.e. 25±2, 27±2, 30±2 and 32±2 °C.

Total larval periods (duration between parasitization to start of pupation) at 25±2, 27±2, 30±2 and 32±2 °C were 6.0 ±1.12, 5.80 ± 1.05, 5.84 ± 1.00 and 5.58 ± 1.91 days, respectively. Whereas the average oviposition and post-oviposition periods were observed to be 24.72 ± 4.37 and 3.27 ± 1.03 days at 25±2 °C, 24.20 ± 4.61 and 3.19 ± 1.05 days at 27±2 °C, 24.08 ± 3.91 and 2.95 ± 0.95 days at 30±2 °C and 22.80 ± 4.81 and 2.73 ± 0.57 days at 32±2 °C. The maximum fecundity was recorded 88.36 ± 33.80 crawlers at 25±2 °C, followed by reduction with increasing

temperatures, 86.36 ± 32.72 crawlers at 27 ± 2 °C, 85.84 ± 30.67 crawlers at 30 ± 2 °C and 83.48 ± 27.36 crawlers at 32 ± 2 °C. The female longevity was maximum i.e. 27.99 ± 6.42 days at 25 ± 2 °C and then decreased with increasing temperatures: 27.39 ± 5.43 days at 27 ± 2 °C, 27.03 ± 4.92 days at 30 ± 2 °C and 25.53 ± 4.37 days at 32 ± 2 °C days. Similarly male longevity was higher 6.73 ± 1.13 days at 25 ± 2 °C, and then decreased with increasing temperatures i.e. 6.54 ± 0.98 days at 27 ± 2 °C, 6.25 ± 1.36 days at 30 ± 2 °C and 5.86 ± 0.67 days at 32 ± 2 °C days. The sex ratio was 1:2 at 25 ± 2 and 27 ± 2 °C, while it was 1:1.5 at 30 ± 2 and 32 ± 2 °C. No literature on the effect of different temperatures on development, longevity, fecundity and sex ratio of *A. bambawalei* is available.

Results indicated that 25 ± 2 °C is the optimum temperature for *A. bambawalei* development among the tested temperatures.

5.5 Toxicity of different insecticidal treatments against *A. bambawalei*

In the present investigation effect of insecticides on the parasitoids was recorded and the results are discussed below.

Zero per cent mortality of *A. bambawalei* was observed in *Verticillium*, *Beauveria*, *Metarrhizium* and buprofezin treatments after 1, 3, 6, 12 and 24 h exposure to treated plates in case of female and male but moderate to high mortality of both female and male parasitoids was noticed after 1h in NSKE (50.00%) and high in clothianidin (85.00%), imidacloprid (82.50%) and thiamethoxam (85.00%) treatments. However, 42.50 per cent mortality of female parasitoid and 45.00 per cent of male in neem oil was observed which was slightly high than females. Dichlorvos, profenophos, triazophos and chlorpyrifos caused 100 per cent mortality within 1h in both sexes. Similarly,

moderate mortality of *A. bambawalei* female and male after 3h exposure was observed as 52.50 per cent and 62.50 per cent in neem oil treatments. In other treatments female and male mortality was: 60.00 and 67.50 per cent in NSKE, 70.00 and 87.50 per cent in imidacloprid, 82.50 and 92.50 per cent in thiamethoxam, 87.50 and 92.50 per cent in clothianidin, respectively. Whereas, female and male mortality after 6 hour was: 62.50 and 72.50 per cent in neem oil, 70.00 and 75.00 per cent in NSKE, 85.00 and 100.00 per cent in imidacloprid, 92.50 and 100.00 per cent in clothianidin, 100.00 per cent in thiamethoxam, respectively. While, mortality after 12 hour in female and male was: 75.00 and 92.50 per cent in neem oil, 77.50 and 87.50 per cent in NSKE, 100.00 per cent in imidacloprid, 100 per cent in clothianidin, 100.00 per cent in thiamethoxam in both the sexes, respectively. However mortality after 24 hour in both the sexes was 100% in neem oil, NSKE, imidacloprid, clothianidin, thiamethoxam, respectively.

The results of present findings are in agreement with the findings of Nalini and Manickavasagam (2011). Mani (1992) exposed mealybug parasitoids like *Aenasius advena* Compere and *Blepyrus insularis* (Cam.) to the guava leaves treated with different insecticides. Diazinon (0.05%) was found to be non-toxic to *A. advena* and least toxic to *B. insularis*. The other chemicals such as endosulfan (0.07%), phosalone (0.07%) and dichlorvos (0.20%) showed lesser toxic residual effect while chlorpyrifos (0.05%), carbaryl (0.10%) and fenthion (0.10%) recorded significantly higher residual toxic effect to both the parasitoids. The low toxicity of IGRs like buprofezin 25 SC was confirmed by Raymond and Dickinson (2006) who reported that buprofezin, pyriproxyfen, and flonicamid were not harmful to *Leptomastix dactylopii* when applied at the label rate. Both buprofezin and

flonicamid were not toxic to *L. dactylopii* with 100 per cent adult survival after 72 h. Dinotefuran was extremely detrimental to the adult parasitoid at the label rate with 100 percent mortality after 24 h. Toxicity of organophosphate and other insecticides to mealybug parasitoids was also confirmed by Walton and Pringle (1999) who reported that, insecticides like chlorpyrifos, endosulphan, cypermethrin were highly toxic to parasitoid of vine mealybug, *Coccidoxenoids peregrinus* (Timberlake) in South Africa. Similarly, according to Hanchinal (2010) parasitoids emergence was nil in the treatments thiodicarb 75 WP, profenophos 50 EC, quinalphos 25 EC, acephate 75 SP and chlorpyrifos 20 EC indicating their detrimental effects on them. However, parasitoid emergence was observed in the treatments viz. buprofezin 25 SC, neem oil, Neemark 1500 ppm, Fish oil rosin soap and *Verticillium lecanii* because of their less hazardness to mummified mealybugs. Lingappa *et al.* (1972) and Wilkinson *et al.* (1975) have also expressed that the larval and pupal stages of the parasitoids were more tolerant than adult stages.

Neem oil and NSKE caused 100 per cent mortality only after 24h in both the sexes of the parasitoids. This is in agreement with the reports of Lowery and Isman (1995), Naumann and Isman (1996) and Tang *et al.* (2002) who confirmed that neem formulations have minimum toxicity to non target organisms and negative effect on parasitoid survival and emergence.

5.6 Activity of *P. solenopsis* on different host plants and its parasitization percentage

Field surveys were undertaken in September, October and November months during 2009 to assess the occurrence of

mealybug *P. solenopsis* and its parasitoid *A. bambawalei* on cotton and associated weeds and the results are discussed below.

Cotton and nine weed hosts were found to be infested with *P. solenopsis* and parasitization of mealybug by *A. bambawalei* was also observed. Two hundred plants of each host were observed. The per cent infestation of mealybug varied in different months. Infestation was found in September on *Hibiscus* (48.00%) followed by *Mesta* (34.50%), *Gossypium* (26.00%) and lowest on *Xanthium* (8.50%). Infestation of mealybug was increased in October month and it was highest on *Hibiscus* (61.50%) followed by *Mesta* (60.50%), *Gossypium* (28.50%) and *Acalypha* (28.00%) whereas, it was minimum on *Xanthium* (5.50%). In November month maximum infestation was found on *Hibiscus* (39.50%) and lowest on *Amaranthus* (4.50%).

In 2009 the highest parasitization of mealybug by *A. bambawalei* was found on *Hibiscus* (10.22%) followed by *Mesta* (8.00%), *Parthenium* (7.77%) and minimum on *Ephorbia geniculata* (3.72%) in September. However, in October maximum parasitization was found on *Hibiscus* (7.81%) followed by *Mesta* (7.69%) and minimum on *Parthenium* (5.48%) while, in November maximum parasitization was found on *Mesta* (10.00%) followed by *Hibiscus* (7.50%) and minimum on *Lantana* (2.85%). No infestation was found on *Xanthium*.

The present findings are in agreement with findings of various workers: Prasad *et al.* (2011) reported that in September month highest infestation of mealybug and parasitization of *A. bambawalei* was observed in roadside fields adjacent to cotton followed by cotton fields adjacent to crop fallows. Arif *et al.* (2009) recorded 154 plant species including 64 weed species as hosts which were categorized as year round hosts, summer (early season) and winter (late season) hosts. Aheer *et al.* (2009)

reported that *H. rosa sinensis* is a preferred, regular and summer host for *P. solenopsis* at Warangal and is mostly prevalent in backyards of many village households.

Removal of Mesta and *Hibiscus* from the adjoining areas of cotton for preventing outbreak of mealybug *P. solenopsis* could be an important strategy for mealybugs management as they are most preferred hosts.

5.7 Evaluation of different insecticides and biopesticides for the management of cotton mealybug *P. solenopsis*

Biological control is considered as the effective long term solution to the mealybug infestation. However, mealybug outbreaks require the use of insecticides due to their rapid multiplication rate as compared to the predators and parasitoids (Wysoki *et al.*, 1981). In this regard, efficacy of insecticides and other biopesticides against mealybug was conducted on *Bt* cotton *var.* RCH-2 *Bt* under field conditions and results based on pooled data obtained from two season experiments conducted on cotton during *Kharif*, 2008 and 2009 are presented and discussed hereunder.

Performance of spray treatments *viz.*, neem oil @ 2000 ml ha⁻¹ NSKE @ 25000 g ha⁻¹, *V. lecanii* @ 2000 g ha⁻¹, *M. anisopliae* @2000 g ha⁻¹, *B. bassiana* @2000 g ha⁻¹, dichlorvos @ 1000 ml ha⁻¹, clothianidin @ 150 g ha⁻¹, Buprofezin @ 1250 ml ha⁻¹, profenophos @1500 ml ha⁻¹, imidacloprid @ 200 ml ha⁻¹, thiamethoxam @ 200 g ha⁻¹, triazophos @ 625 ml ha⁻¹ and chlorpyrifos @ 1500 ml ha⁻¹ was judged on the basis of infestation of mealybugs (No./10 cm apical shoot) recorded at 3, 7, 10 and 14 days after spray (DAS). Pooled data of two experiments was used for efficacy comparison.

The overall initial mean count of mealybugs in untreated control plants was 115.36 mealybugs/10 cm apical shoot that rose to 119.23 mealybugs. All insecticide treatments significantly lowered the incidence of mealybugs. However, better efficacy of profenophos 50 EC @ 1500 ml ha⁻¹ was noticed up to 10 DAS as the count at three, seven and ten days after spray was 33.88, 17.00 and 13.99 mealybugs/ 10 cm apical shoot, respectively. This treatment was at par with chlorpyrifos 20 EC @ 1500 ml ha⁻¹ which recorded 36.27, 19.35 and 18.58 mealybugs, respectively. The next effective treatment was dichlorvos 76 EC @ 1000 ml ha⁻¹ which recorded 40.86 and 22.89 mealybugs three and seven days after spray followed by triazophos 40 EC @ 625 ml ha⁻¹ wherein 43.03 and 24.39 mealybugs were found after three and seven days after spray, respectively. Both these treatments were at par with each other. Next promising treatments were imidacloprid 17.8 SL @ 200 g ha⁻¹ (47.86 and 29.27 mealybugs) and clothianidin 50 WDG @ 150 g ha⁻¹ (49.40 and 31.07 mealybugs) at three and seven days after spray, respectively.

Ten and fourteen days after spray, population of mealybug was slightly increased in dichlorvos 76 EC (22.98 and 28.73 mealybugs), triazophos 40 EC (24.61 and 30.69 mealybugs), imidacloprid 17.8 SL (31.21 and 35.66 mealybugs), clothianidin 50 WDG (33.26 and 38.09 mealybugs), thiamethoxam 25 WG (31.86 and 38.64 mealybugs), NSKE 5 per cent (60.74 and 68.08 mealybugs) and neem oil (65.75 and 71.95 mealybugs). Buprofezin 25 SC @1250 ml ha⁻¹ had recorded significantly lowest population of 16.41 mealybugs/10 cm apical shoot at 14 DAS.

The present findings are in line with findings of Bhosle *et al.* (2009) who reported that out of 12 insecticides tried as

curative spray, acephate 70 SP, followed by profenophos 50 EC and dichlorvos 76 EC were effective in the management of mealybug at 2, 7 and 14 days. Bedford *et al.* (1996) recorded that infestation was significantly reduced and the effects on mealybugs were greater with buprofezin application. Similarly, Balikai (2002 and 2005) observed that buprofezin 25 SC @ 1000 and 1125 ml ha⁻¹ recorded maximum control of 80.4 per cent of mealybug, *M. hirsustus* population on grape when sprayed along with fish oil rosin soap (Meenark) @ 3125 g ha⁻¹. Results obtained by Muthukrishnan *et al.* (2005) indicated that buprofezin 25 SC sprayed thrice @ 1125 and 1500 ml ha⁻¹ at 15 days interval reduced the congregation of *M. hirsustus* on grape and increased the yield. Dhawan *et al.* (2009) made studies on persistence and residual toxicity of insecticides at recommended concentrations in field on cotton against first instar and adult mealybug *P. solenopsis*. Based on the index of persistence toxicity, the order of effectiveness for the crawlers of *P. solenopsis* was profenophos (637.1) > thiodicarb (587.9) > buprofezin (492.3) > quinalphos (407.9) > chlorantraniliprole (380.0) > Spirotetremate (371.6) > acephate (345.7) > carbaryl (314.6) > chlorpyrifos (273.4). Similarly, for the adult this order of effectiveness was profenophos (572.9) > buprofezin (483.1) > thiodicarb (430.0) > quinalphos (379.9) > chlorantraniliprole (371.6) > spirotetremate (361.3) > acephate (296.7) > carbaryl (260.0) > chlorpyrifos (252.3). Agarwal *et al.* (2009) recorded that profenophos 50 EC (check) recorded 93.73 per cent mortality over control and was at par with spirotetramat (12%) + imidacloprid (36%)- 480 SC (85.09% mortality) and thiodicarb 75 WP @ 750 g a.i ha⁻¹ (84.48% mortality) after three days of second spray. The mortality of mealybug due to single molecule at different doses ranged between 53.04 and 62.39 per cent while the check (profenophos 50 EC) showed the promising results as compared to other

treatments after the first spray. Similarly, Patel *et al.* (2010) reported that more than 95 per cent reduction in mealybug population over control was observed after three days after spray in buprofezin at all the three doses (250, 312.5 and 625 g a.i ha⁻¹) tested. Profenophos 50 EC was also found effective by Suresh *et al.* (2010) who reported that profenophos and methyl parathion were found to be quite effective and caused 100 per cent mortality of *P. solenopsis* on one day after treatment while imidacloprid, fish oil rosin soap and dimethoate caused cent per cent mortality after two days of the spray application. All the tested insecticides were found to be quite effective up to 10 days of the application. *Beauveria* was found to be moderately effective and caused 77 per cent mortality after 10 days of treatment. The results of the present findings are in line with the above workers.

The effectiveness of dichlorvos in the present study is also in conformity with Narsimha Rao *et al.* (1977) who recorded that dichlorvos (0.15%) with combination of fish oil rosin soap (2.5%) gave 80 per cent mortality of mealybugs. Mani (1990) reported that sprays of dichlorvos (0.02%) in combination with fish oil rosin soap @ 2.5 per cent helped to control *M. hirsutus* on grapevine. Zaka *et al.* (2006) worked on the relative efficacy of different pesticides against cotton mealybug in Pakistan. They concluded that methomyl, triazophos and methamidophos were the most effective pesticides against cotton mealybug, followed by imidacloprid. Whereas, Tanwar *et al.* (2007) gave a report on recent mealybug infestations on various economic crops in India. A number of pesticides were tested against these pests: lamdacyhalothrin (Boxer, 2.5 EC), bifenthrin (Talstar, 10 EC), profenophos (Craker, 50 EC), imidacloprid (Crown, 200 SL), abamectin (Alarm, 1.8 EC), emamectin benzoate (Proclaim, 19 EC), chlorpyrifos (Lorsban, 40 EC), mathidathion (Supracide, 40 EC), acetamiprid (Rani, 20 EC) were tested in a laboratory

bioassay and then in the field. After 72 hours profenophos was most effective, followed by mathidathion and bifenthrin (with mortality rates of 68.34, 65.83 and 48.23 %, respectively). Saeed *et al.* (2007) reported that the recommended application rates of methomyl, profenophos and chlorpyrifos provided the best control; lethal time studies proved their efficiency for timely control of this sporadic pest, profenophos, chlorpyrifos, methomyl and bifenthrin, provided satisfactory control of cotton mealybug.

The literature published on insecticidal activity of *V. lecanii* against mealybug is meager. However, Gonzales *et al.* (1995) reported that, the *V. lecanii* conidia gave very good mortality (84.81%) against *Planacoccus citri* on 10th day. Shelke (2001) observed that, Fish oil rosin soap (0.5%) with *V. lecanii* (0.4%) or *C. montrouzieri* was the safest and most suitable treatment against grapevine mealybug, *M. hirsutus*. Jayachakravarthy (2002) reported that, the fungus, *V. lecanii* caused 80.20 per cent mortality of some sucking pests at 2×10^5 CFU/ml dose in Maharashtra State within two weeks. According to Koli (2003), *V. lecanii* WP @ 0.3% was found to be best against nymphs and adults of grape mealybug. The results of the present study are in line with the above workers.

The effectiveness of *Metarhizium anisopliae* was also corroborative with Kharbade *et al.* (2009) who recorded that *Metarhizium anisopliae* @ 2000 gm/ha was most effective by recording minimum of 87.46 mealybugs/ 5 cm shoot tip length/plant. This treatment was statistically on par with Neem oil 2000 ml ha⁻¹ and Dashparni @ 10% in which average of 108.73 and 110. 33 mealybugs/ 5 cm shoot tip length/ plants were noticed, respectively. The higher seed cotton yield of 1521 kg ha⁻¹

was obtained in treatment with *M. anisopliae* @ 2000 gm ha⁻¹ as against 913 kg/ha in untreated control.

The neem products were found comparatively less effective as compared to conventional insecticides and biopesticides. However, neem oil 4 per cent (Hussain *et al.*, 1996), NSKE 5 per cent (Verghese, 1997), extracts from *Azadirachta indica* (Satyanarayana *et al.*, 2003), NSKE 4 per cent (Koli, 2003) were effective against mealybugs on various fruit crops.

The efficacy of profenophos 50 EC, buprofezin 25 SC and chlorpyrifos 20 EC was well reflected on seed cotton yield. These three treatments recorded significantly maximum seed cotton yield at all the dosages in both the years. These two chemicals after each spray effectively controlled mealybug population. The present findings on higher seed cotton yield are in accordance with Bhosle *et al.* (2009) who evaluated 12 insecticides as curative spray and reported that profenophos 50 EC and acephate 70 SP were effective in controlling the mealybug with higher seed cotton yield of 22.2 q ha⁻¹ in both the treatments which were at par with each other.

Insect growth regulators (IGRs) represent the newest approach to operational and commercial insect control. Buprofezin, being biorational insecticide, offered both effective control of mealybug and selectivity to many of the beneficial insects and have a novel mode of action. It was effective against all the stages of mealybug and useful in pest resistance management. Similarly profenophos and chlorpyrifos were effective against mealybug. Efficacies of these insecticides were increased when second spray was given within a week after first spray because it controlled the overlapping generations of mealybug effectively. Buprofezin having low impact on beneficial insects is ideally suited for mealybug management when

population is low and profenophos is effective whenever mealybug outbreaks on cotton are observed both the insecticides can be used alternatively one after the other. These three insecticides can be used judiciously in IPM program of mealybug on cotton.

The economic analysis of the usage of chemicals is required for advising the farmers for getting higher net profit. In the present study economic analysis revealed that profenophos, buprofezin and chlorpyrifos were found to be effective for the management of mealybugs on cotton. Profenophos 50 EC, buprofezin 25 SC and chlorpyrifos 20 EC recorded maximum net gain of Rs. 35,760 ha⁻¹, Rs. 32,272 ha⁻¹ and Rs. 32,550 ha⁻¹, respectively compared to untreated control during *Kharif*, 2008 while during *Kharif*, 2009 profenophos, chlorpyrifos and buprofezin obtained the net gain of Rs. 43,600/-, Rs. 42,410/- and Rs. 42,415/- respectively.

Buprofezin has been found to be quite effective against *P.solenopsis* and is also not as toxic as the synthetic insecticides towards its parasitoid. Thus, buprofezin can be used in developing an IPM program to effectively manage the cotton mealybug without adversely affecting the environment.

6. SUMMARY AND CONCLUSIONS

6.1 Summary

The cotton mealybug *P. solenopsis* Tinsley (Homoptera: Pseudococcidae), a newly introduced pest, has become a serious pest of cotton in Maharashtra during last 4 to 5 years.

The present studies entitled “Studies on biology, mass multiplication and management of cotton mealybug *Phenacoccus solenopsis* Tinsley and its parasitoid” were carried out during *Kharif*, 2008 and *Kharif*, 2009 both in the laboratory as well as on Research Farm of the Department of Entomology, Post Graduate Institute, Mahatma Phule Krishi Vidyapeeth, Rahuri. The study generated the information on biology, development, longevity and mass production of both the mealybug and *Aenasius bambawalei* Hayat and other aspects like, toxicity of different insecticidal treatments against *A. bambawalei*, the efficacy of some insecticides including IGR, neem oil, NSKE, entomophagus pathogen i.e. *Verticillium lecanii*, *Beauveria bassiana* and *Verticillium lecanii* in the suppression of mealybug. The biology of mealybug on sprouted potato and its parasitoid was studied in the laboratory at temperature 25 ± 2 °C and 65 ± 5 RH, while observations on management of cotton mealybug were recorded under field condition. The results of these investigations are summarized here under.

6.1.1 Biology of *P. solenopsis*

Observations on biology of *P. solenopsis* on potato sprouts indicated that the pest reproduced parthenogenetically. Males had two nymphal instars, pupa (cocoon) and adult stage whereas female had three nymphal instars and adult stage. Adult

female was wingless and larger in size (3.90 ± 0.06 mm in length and 2.05 ± 0.04 mm in width) as compared with male which was winged and smaller in size (1.10 ± 0.06 mm in length and 0.20 ± 0.02 mm in width). The mean duration was 4.84 ± 0.75 , 6.22 ± 1.19 and 4.76 ± 0.91 days for first, second and third female nymphal instar, respectively. For male, it was 4.60 ± 0.87 , 7.42 ± 1.55 and 7.20 ± 1.32 days for the first, second instar and pupa (cocoon), respectively. The male was short lived with an adult life of 2.08 ± 0.59 days, while female lived longer (21.02 ± 3.02) days. On an average, male and female completed their life cycle in 21.30 ± 4.33 and 36.84 ± 5.87 days, respectively. The adult female had a pre-oviposition, oviposition and post-oviposition period of 3.78 ± 0.69 , 14.28 ± 1.65 and 2.96 ± 0.68 days, respectively. Mealybug formed 4 to 7 ovisacs during its life span in which 312 to 860 eggs, with a mean of 594.84 ± 64 , were deposited which hatched within a mean of 2.92 ± 1.11 minutes and male to female sex ratio was 1:3.

6.1.2 Biology of *A. bambawalei*

Biology of *A. bambawalei* on mealybug *P. solenopsis* maintained on sprouted potato indicated that it is solitary endoparasitoid i.e. emerged only one parasitoid from each parasitized mealybug. Adult female parasitoid was larger in size (1.81 ± 0.21 mm in length, 0.78 ± 0.05 mm in width and 0.84 ± 0.05 mm head width) as compared with male which was smaller in size (1.20 ± 0.12 mm in length, 0.39 ± 0.04 mm in width and 0.44 ± 0.05 mm in head width). Pupa was barrel shaped, dark brown in colour (3.37 ± 0.06 mm length and 1.78 ± 0.05 mm width) and pupal period ranged from 4 to 7 days in male and 6 to 10 days in female. The mean development of female parasitoid was completed in 15.16 ± 1.57 days and 11.54 ± 1.81 days in male. The male was short lived with an adult longevity of 6.49 ± 1.16 days,

while female lived longer (27.11 ± 5.31) days. On an average, male and female completed their life cycle in 17.79 ± 3.17 and 40.27 ± 7.52 days, respectively. The adult female had oviposition and post-oviposition period of 24.04 ± 4.34 and 3.07 ± 0.96 days, respectively. Adult female parasite parasitized 25 to 155 mealybugs during entire life cycle and male to female sex ratio was 1:2.

6.1.3 Mass multiplication of *P.solenopsis*

Three different prominent hosts i.e. cotton plant, *Hibiscus* and sprouted potato were used for mass multiplication of *P.solenopsis* as a food for *A.bambawalei* at a temperature of 25 ± 2 °C and RH 65 ± 5 per cent.

Among different hosts used, maximum individuals reached to adult in potato sprout were 87.50% followed by *Hibiscus* 80.83% and cotton 79.16%. Total nymphal period on cotton, *Hibiscus* and potato was 16.78 ± 2.65 , 17.66 ± 2.41 and 15.82 ± 2.66 days, respectively. The average pre-oviposition, oviposition and post-oviposition periods were observed to be 5.16 ± 0.75 , 10.44 ± 1.94 and 2.64 ± 0.49 days on cotton, 4.92 ± 0.76 , 12.40 ± 1.68 and 2.84 ± 0.37 days on *Hibiscus* and 3.78 ± 0.69 , 14.28 ± 1.65 and 2.96 ± 0.68 days on sprouted potato. Maximum fecundity of the mealybug was recorded on potato sprouts (594.84 ± 163.65 crawlers), followed by *Hibiscus* (492.8 ± 110.92 crawlers), and cotton (481.6 ± 92.32 crawlers). However, female longevity was 21.02 ± 2.34 days on potato followed by 20.16 ± 2.44 days on *Hibiscus*, and 18.24 ± 2.18 days on cotton. Similarly, male longevity was noticed 2.08 ± 0.59 days on potato, followed by 1.92 ± 0.75 days on *Hibiscus*, and 1.76 ± 0.77 days on cotton days. Sex ratio was 1:3 on cotton, 1:3 on potato sprouts and 1:2.2 on *Hibiscus*. The individuals reared on potato sprouts had higher pre-oviposition period, oviposition period and adult female longevity

and fecundity as compared with those reared on cotton and *Hibiscus*. It indicated that rearing of *P. solenopsis* was easier on potato sprouts and multiplication of the pest was faster on it as compared to other two hosts.

Another lab experiments were carried out to study the development rates of *P. solenopsis* at different constant temperatures i.e. 25 ± 2 , 27 ± 2 , 30 ± 2 and 32 ± 2 °C. Total nymphal periods of *P. solenopsis* at 25 ± 2 , 27 ± 2 , 30 ± 2 and 32 ± 2 °C were 16.44 ± 2.74 , 16.25 ± 2.29 , 15.75 ± 1.83 and 16.02 ± 2.36 days, respectively. The average pre-oviposition, oviposition and post-oviposition periods were observed to be 5.24 ± 0.66 , 10.96 ± 2.17 and 2.72 ± 0.46 days at 25 ± 2 °C, 4.96 ± 0.61 , 10.24 ± 1.69 and 2.52 ± 0.51 days at 27 ± 2 °C, 4.68 ± 0.69 , 9.72 ± 1.95 and 2.36 ± 0.49 days at 30 ± 2 °C and 4.28 ± 0.94 , 9.20 ± 1.61 and 2.08 ± 0.76 days at 32 ± 2 °C. Maximum fecundity, 487.60 ± 92.34 crawlers was recorded at 25 ± 2 °C, followed by reduction with increasing temperature. The female longevity was maximum i.e. 18.92 ± 2.06 days at 25 ± 2 °C, and then decreased with increasing temperature. Similarly, male longevity was higher, 2.40 ± 0.58 days at 25 ± 2 °C, and then decreased with increasing temperatures. A higher female biased sex ratio occurred at all temperatures except 32 ± 2 °C. However, sex ratio did not demonstrate any trend (except 32 ± 2 °C 1:2.3). The individuals reared at 25 ± 2 °C had higher pre-oviposition period, oviposition period and adult female longevity and fecundity as compared with those reared at 27 ± 2 , 30 ± 2 and 32 ± 2 °C. It indicated that among the different temperature conditions, 25 ± 2 °C was the most favorable temperature for rearing of mealybug *P. solenopsis*.

6.1.4 Mass multiplication of *A. bambawalei*

Present study was conducted to determine host (*P. solenopsis*) stage preference to parasitoid *A. bambawalei*

maintained on sprouted potatoes. The *A. bambawalei* parasitized all host stages except first instar host stage during oviposition. The results showed that maximum parasitization percentage (91.00%) was recorded on third instar nymph followed by adult mealybug (81.20%), second instar nymph (31.00%) while no parasitization was observed in first instar nymph of mealybug. Parasitoid preferred 3rd instar and adults host for parasitization. Sex ratio of male to female was (3:2) on second instar mealybug, 1:1.5 on third instar and 1:2 on adult mealybug.

Other lab experiments were carried out to study the development rates of *A. bambawalei* at different constant temperatures i.e. 25 ± 2 , 27 ± 2 , 30 ± 2 and 32 ± 2 °C. The mean fecundity was maximum, 88.36 ± 33.80 (parasitized mealybugs) at 25 ± 2 °C and found to be decreased with increasing temperature. The total average larval period was 6.0 ± 1.12 days at 25 ± 2 °C followed by 5.80 ± 1.05 days at 27 ± 2 °C, 5.84 ± 1.0 days at 30 ± 2 °C and 5.58 ± 1.91 days at 32 ± 2 °C. The mean oviposition and post-oviposition period was 24.72 ± 4.37 and 3.27 ± 1.03 days at 25 ± 2 °C and found to be less in subsequent temperatures. Male and female longevity was 6.73 ± 1.13 and 27.99 ± 6.42 days at 25 ± 2 °C followed decrease in longevity with increasing temperatures. The sex ratio was 1:2 at 25 and 27 ± 2 °C, while 1:1.5 at 30 ± 2 and 32 ± 2 °C. The results indicated that third instar mealybug is the most suitable host stage for mass rearing of *A. bambawalei* and produced more female progeny as compared with other two host stages of mealybug and the individuals reared at 25 ± 2 °C had higher oviposition period and adult female longevity and fecundity as compared with those reared at 27 ± 2 , 30 ± 2 and 32 ± 2 °C. Therefore, 25 ± 2 °C was the most favorable temperature for rearing of mealybug parasitoid *A. bambawalei*.

6.1.5 Toxicity of different insecticides against *A. bambawalei*

Toxicity of different insecticides on parasitoids *A. bambawalei* was evaluated and results indicated that zero per cent mortality of *A. bambawalei* was observed in *Verticillium*, *Beauveria*, *Metarrhizium* and buprofezin treatments after 1h, 3h, 6h, 12h and 24h after exposure to treated plates both in female and male but moderate mortality of both female and male parasitoids was noticed after 1h in NSKE (50.00%), clothianidin (85.00%), imidacloprid (82.50%) and thiamethoxam (85.00%). However, 42.50% mortality of female and 45.00% of male in neem oil was observed which was slightly high. Dichlorvos, profenophos, triazophos and chlorpyrifos caused 100% mortality within 1h in both sexes, indicating their detrimental effects on parasitoids. The exposure to dichlorvos, profenophos, triazophos and chlorpyrifos was highly toxic to parasitoids. Among the chemicals tested *Verticillium*, *Beauveria*, *Metarrhizium* and buprofezin were safest biopesticides to the parasitoid *A. bambawalei*, while NSKE, neem oil, clothianidin and imidacloprid were less toxic to parasitoid.

Hence, it indicated that whenever activity of this parasitoid was observed the use *Verticillium*, *Beauveria*, *Metarrhizium*, NSKE, neem oil and Buprofezin would be appropriate. If no parasitoid activity is observed, then clothianidin, imidacloprid may be used.

6.1.6 Activity of *P. solenopsis* on different host plants and its parasitization percentage

Field surveys during *Kharif*, 2009 on cotton and associated weeds were taken in September, October and November months indicated that Cotton and nine weed hosts

were found infested with *P. solenopsis* and parasitization of mealybug by *A. bambawalei* was also observed. Infestation was found in September on *Hibiscus* (48.00 %) followed by *Mesta* (34.50 %), *Gossypium* (26.00 %) and lowest on *Xanthium* (8.50 %). Infestation of mealybug was increased in October month and it was highest on *Hibiscus* (61.50 %) followed by, *Mesta* (60.50 %), *Gossypium* (28.50%) and *Acalypha* (28.00 %) whereas, it was minimum on *Xanthium* (5.50 %). In November month maximum infestation was found on *Hibiscus* (39.50 %) and lowest on *Amaranthus* (4.50 %). In 2009 the highest parasitization of mealybug by *A. bambawalei* was found on *Hibiscus* (10.22%) followed by *Mesta* (8.00%), *Parthenium* (7.77 %) and minimum on *Ephorbia geniculata* (3.72 %) in September. However, in October maximum parasitization was found on *Hibiscus* (7.81 %) followed by *Mesta* (7.69 %) and minimum on *Parthenium* (5.48 %) while in November maximum parasitization was found on *Mesta* (10.00 %) followed by *Hibiscus* (7.50 %) and minimum on *Lantana* (2.85 %). No infestation was found on *Xanthium*. Results indicated that different host plant species were found severely infested with the mealybug and noticeable parasitoid activity was recorded during different months of the year in the cotton agro-ecosystem.

The finding enables the effective integrated pest management of mealybug because the carryover of the pest in off-season on weeds can be suppressed if such weed hosts are destroyed during cultivation that can prevent future outbreak of mealybug.

6.1.7 Evaluation of different insecticides and biopesticides for the management of cotton mealybug *P. solenopsis*

Efficacy of insecticides and other biopesticides against mealybug was evaluated on *Bt* cotton under field conditions and results based on pooled data obtained from two season experiments conducted on cotton during *Kharif*, 2008 and *Kharif*, 2009. The findings are summarized hereunder.

Thirteen insecticides and biopesticide *viz.*, neem oil @ 2000 ml ha⁻¹ NSKE @ 25000 g ha⁻¹, *V. lecanii* @ 2000 g ha⁻¹, *M. anisopliae* @ 2000 g ha⁻¹, *B. bassiana* @ 2000 g ha⁻¹, dichlorvos @ 1000 ml ha⁻¹, clothianidin 150 g ha⁻¹, buprofezin @ 1250 ml ha⁻¹, profenophos @ 1500 ml ha⁻¹, imidacloprid @ 200 ml ha⁻¹, thiamethoxam @ 200 g ha⁻¹, triazophos @ 625 ml ha⁻¹ and chlorpyrifos @ 1500 ml ha⁻¹ were studied for their bioefficacy against mealybugs. The incidence of mealybugs (no/10 cm apical shoot) of two season revealed that the count of mealybugs before initiation of spray treatment was in the range of 98.03 to 115.36 mealybugs. The untreated control plants showed an increasing mealybug population from 115.36 to 119.23 mealybugs/10 cm apical shoot during a span 14 days. Three, seven and ten days after spray, profenophos 50 EC @ 1500 ml ha⁻¹ recorded lowest mealybug population 33.88, 17.00 and 13.99 mealybugs/10 which was at par with the chlorpyrifos 20 EC @ 1500 ml ha⁻¹ which recorded population 36.27, 19.35 and 18.58 mealybugs/10. Next best treatment was dichlorvos 76 EC @ 1000 ml ha⁻¹ which was followed by triazophos 40 EC and both the treatments were at par with each other. Next promising treatments were imidacloprid 17.8 SL @ 200 g ha⁻¹ followed by clothianidin 50 WDG @ 150 g ha⁻¹ and were at par with each other.

The profenophos 50 EC @ 1500 ml ha⁻¹ and buprofezin 25 SC @ 1250 ml ha⁻¹ were effective in reducing the mealybug population on cotton. Among biopesticides *V.lecanii* gave better

results compared to *B.bassiana* and *M. anisopliae*. The treatments *V. lecanii* @ 2000 g ha⁻¹, *M. anisopliae* @ 2000 g ha⁻¹, *B. bassiana* @2000 g ha⁻¹ and buprofezin @1250 ml ha⁻¹ lowered the pest population effectively upto 14 DAS. Whereas the treatments neem oil @ 2000 ml ha⁻¹, NSKE 5% @ 25000 g ha⁻¹, dichlorvos @1000 ml ha⁻¹, clothianidin @150 g ha⁻¹, imidacloprid @ 200 ml ha⁻¹, thiamethoxam @200 g ha⁻¹ and triazophos @ 625 ml ha⁻¹ lowered the pest population upto 10 DAS.

Profenophos 50 EC @ 1500 ml ha⁻¹, buprofezin 25 SC @ 1250 ml ha⁻¹ and chlorpyrifos 20 EC @1500 ml ha⁻¹ recorded significantly maximum seed cotton yield with higher net returns in both the seasons of study.

6.2 Conclusions

- The present study clearly indicated that mealybug; *P. solenopsis* was ovo-viviparous, producing 312 to 860 crawlers during its total life cycle of 27 to 42 days on potato sprouts.
- The adult female was wingless and lived longer (16 to 26 days) while male was having a pair of wings and short lived (1 to 3 days)
- Incubation period of egg was very short and parthenogenetic reproduction was observed.
- *A. bambawalei* is a solitary endoparasitoid i.e. emergence of only one parasitoid from each parasitized mealybug. Adult female parasitoid was larger in size (1.81× 0.78 mm) as compared with male which was smaller in size (1.20 × 0.39 mm).
- Pupa of *A. bambawalei* was barrel shaped, dark brown in colour, 3.37 mm in length and 1.78 mm in width and pupal

period ranged from 4 to 7 days in male and 6 to 10 days in female.

- The mean development of *A. bambawalei* female parasitoid was completed in 15.16 days and 11.54 days in male.
- The male of *A. bambawalei* was short lived with an adult longevity of 6.49 days, while female lived longer (27.11) days.
- Male and female of *A. bambawalei* completed their life cycle in 17.79 and 40.27 days, respectively. Adult female parasitoid parasitized 25 to 155 mealybugs during entire life cycle.
- For mass multiplication of *P. solenopsis* potato sprouts were the most favorable and easier host as compared to cotton and *Hibiscus* plants.
- The temperature 25 ± 2 °C was the most favorable temperature for rearing of mealybug *P. solenopsis* and multiplication of *A. bambawalei* as compared to other temperature conditions.
- For mass multiplication of *A. bambawalei* 3rd instar host stage is the most suitable and preferred host stage and produced more female progeny as compared with other two stages (1st and 2nd) of the mealybugs.
- Removal of Mesta and *Hibiscus* from the adjoining areas of cotton for preventing outbreak of mealybug *P. solenopsis* could be an important strategy for mealybugs management as they are most preferred hosts.
- Whenever activity of this parasitoid was observed, it is better to use *Verticillium*, *Beauveria*, *Metarrhizium*, NSKE, neem oil and buprofezin. If no parasitoid activity is observed, then clothianidin or imidacloprid can be used.

- Buprofezin, having novel mode of action and less hazardous to the natural enemies, can be used whenever mealybug population noticed during early stage of the crop growth.
- Profenophos and chlorpyrifos can be used as an alternative to buprofezin whenever outbreak of mealybug is noticed. These two insecticides can be used judiciously considering to natural enemies population and to avoid development of resistance in mealybug population.
- Use of profenophos, chlorpyrifos and buprofezin for the management of mealybug on cotton increased the cotton yield significantly and obtained higher returns.
- Buprofezin has been found to be quite effective against *P.solenopsis* and is also not as toxic as the synthetic insecticides towards its parasitoid. Thus, buprofezin can be used in developing an IPM program to effectively manage the cotton mealybug without adversely affecting the environment.

Future line of work

1. Life table studies of cotton mealybug *P.solenopsis* and estimation of crop losses in cotton due to mealybug damage.
2. Survey of mealybug *P.solenopsis* on different hosts and various parasitoids associated with throughout a year.
3. Large scale field augmentation of parasitoid *A.bambawalei* for long term management of mealybug *P.solenopsis*.

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8. VITA

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DOCTOR OF PHILOSOPHY (AGRICULTURE)

in

AGRICULTURAL ENTOMOLOGY

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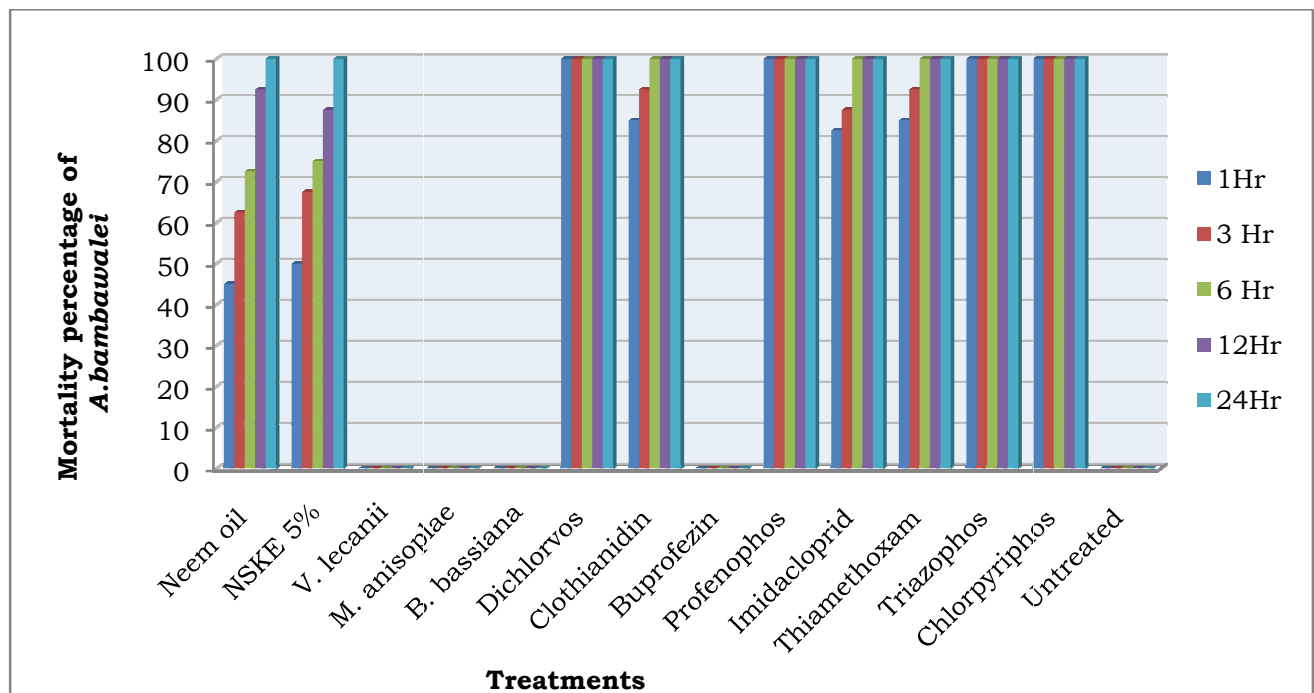


Fig.2: Toxicity of different insecticidal treatment against adult males of *A.bambawalei*

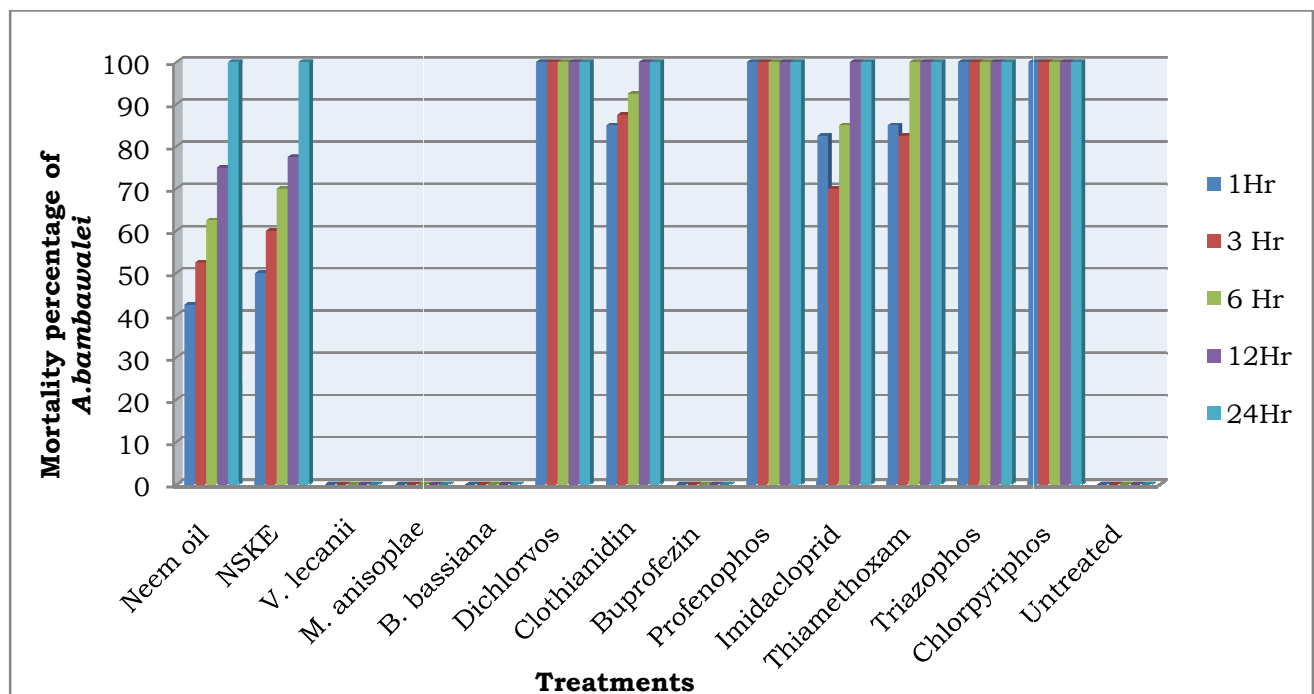


Fig.3: Toxicity of different insecticidal treatment against adult females of *A.bambawalei*

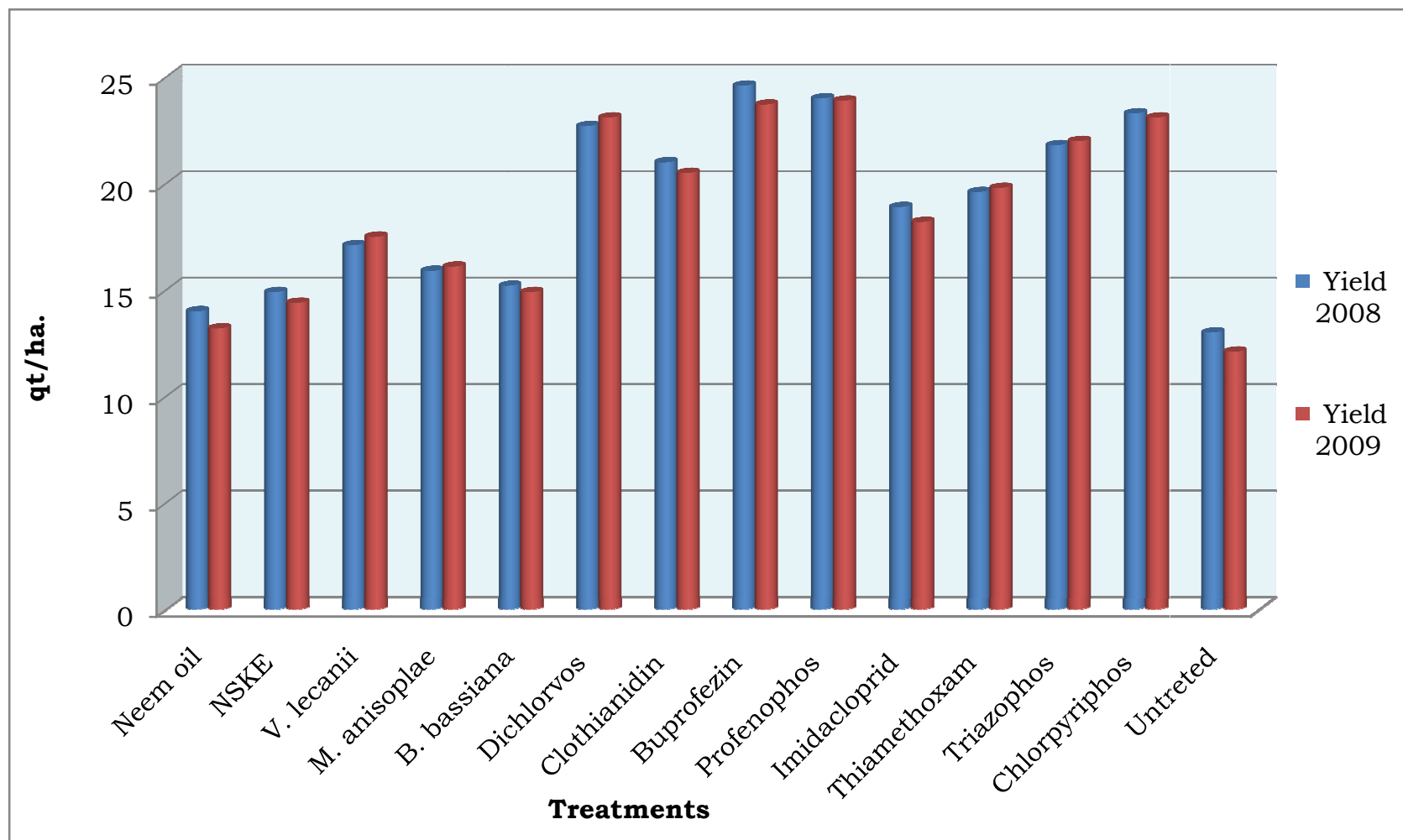


Fig.9: Overall performance of various treatments on seed cotton yield during *Kharif* 2008 and *Kharif* 2009

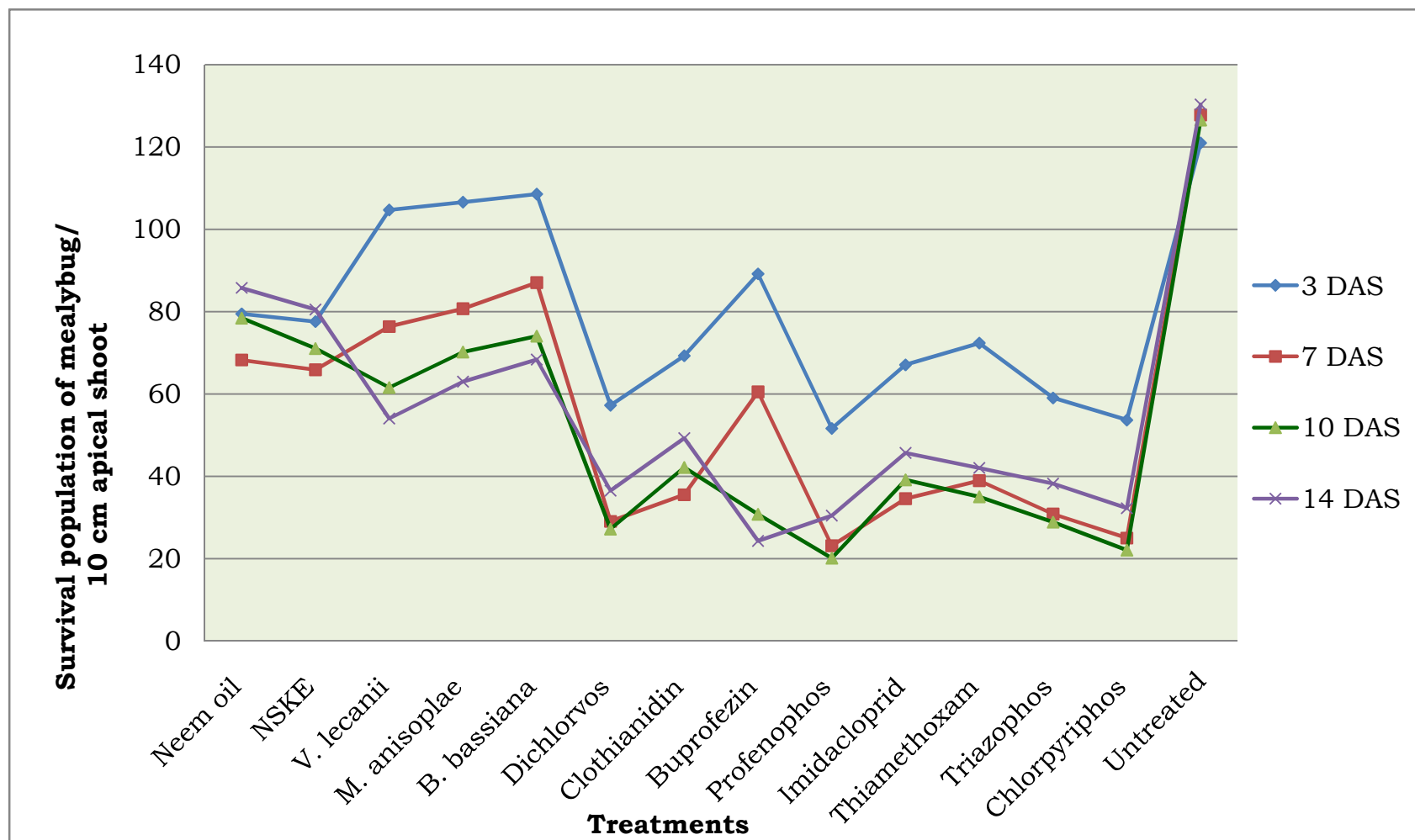


Fig. 4 Effect of different treatments on *P. solenopsis* after first spray (Kharif, 2008)

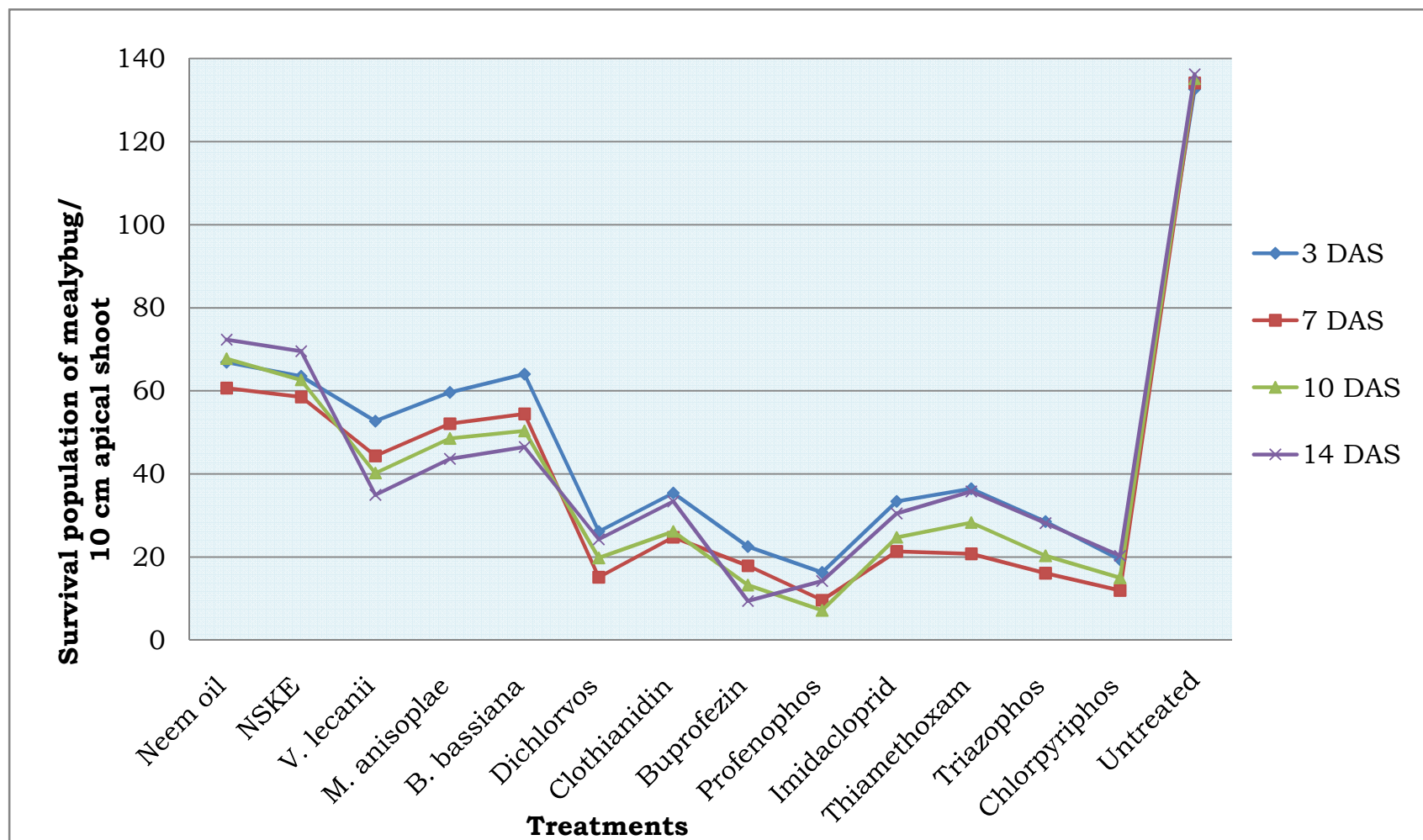


Fig. 5 Effect of different treatments on *P. solenopsis* after second spray (Kharif, 2008)

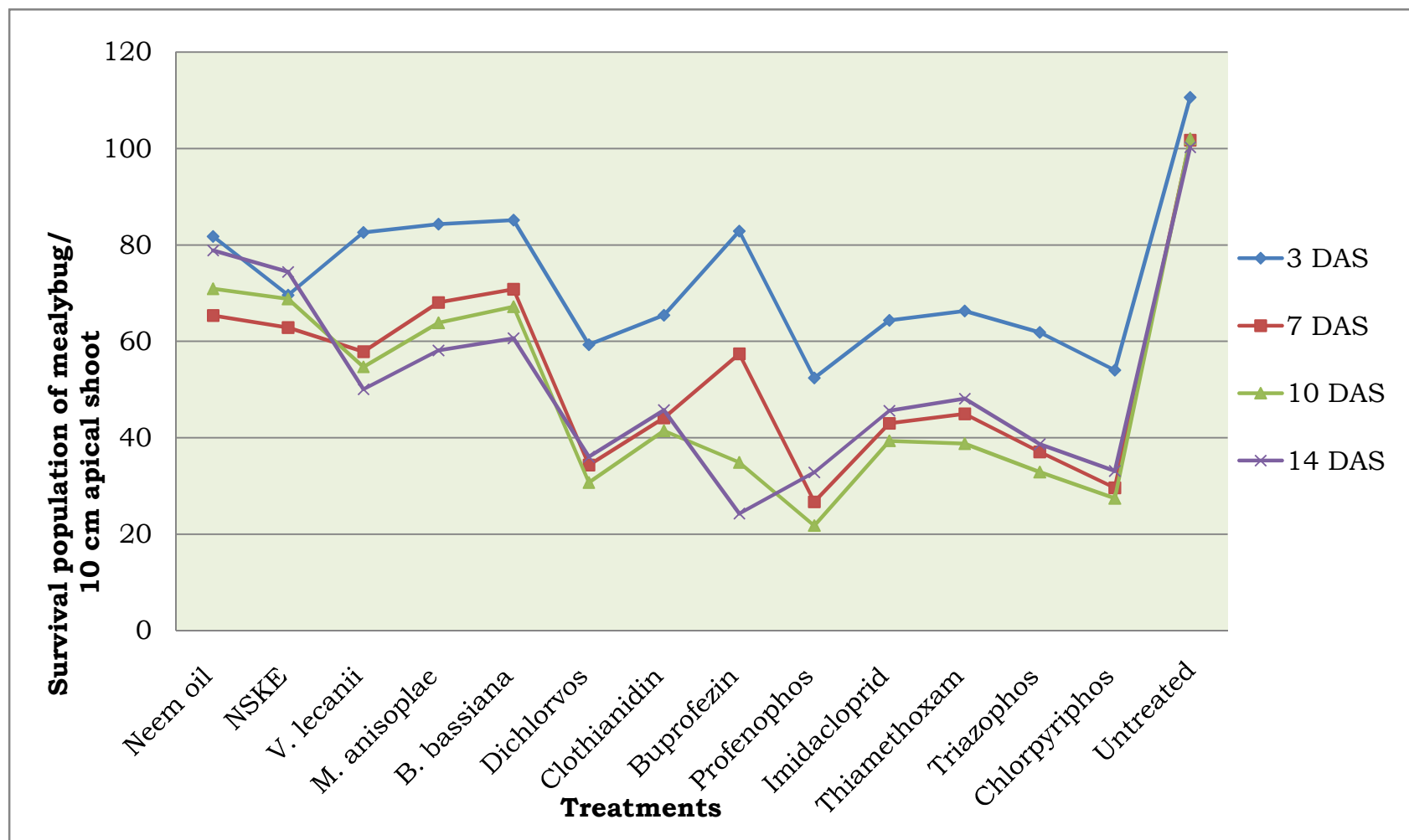


Fig.6 Effect of different treatments on *P.solenopsis* after first spray (Kharif, 2009)

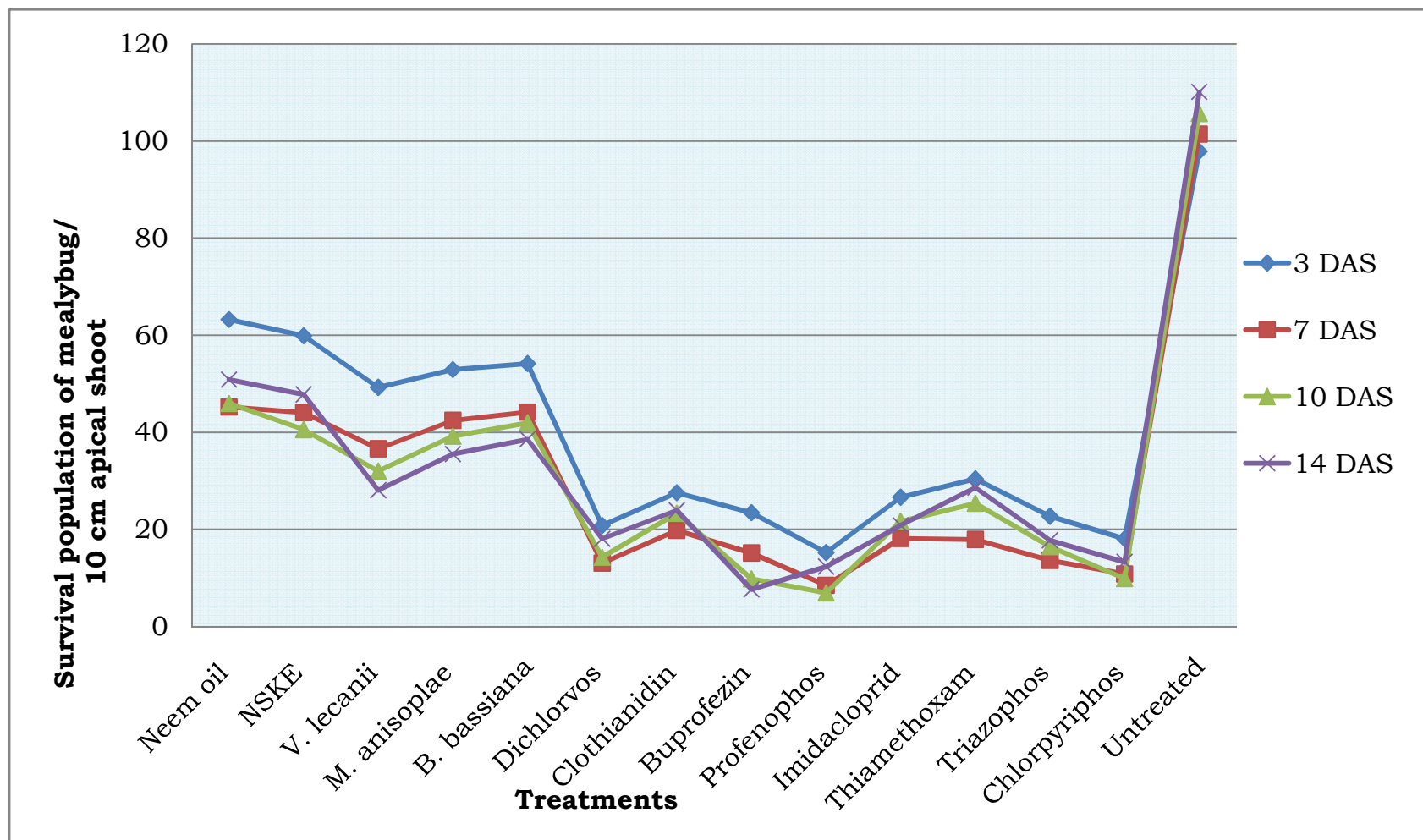


Fig. 7 Effect of different treatments on *P.solenopsis* after second spray (Kharif, 2009)

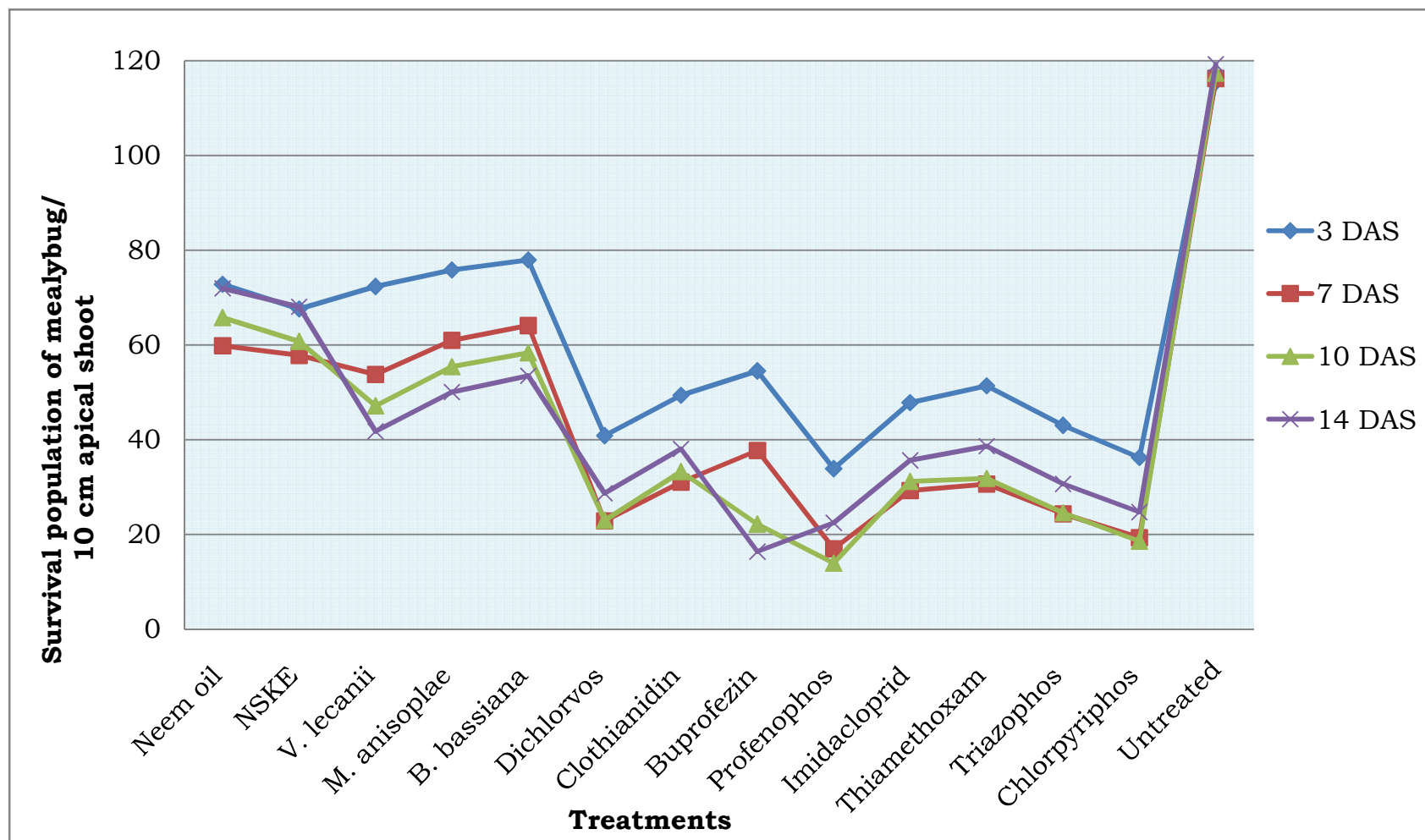


Fig.8 Effect of different treatments on *P.solenopsis* (Pooled data: *Kharif*, 2008 and *Kharif*, 2009)

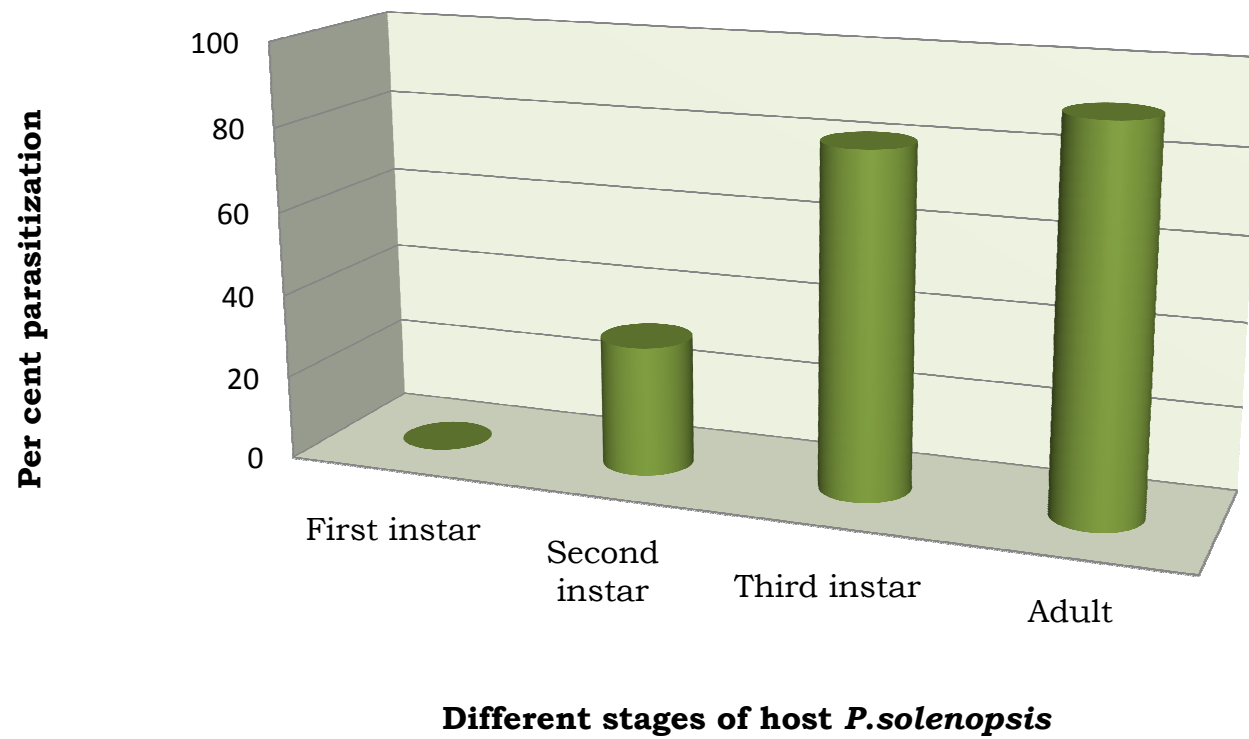


Fig.1: Preference of *A. bambawalei* to different stages of mealybugs *P.solenopsis*



Plate 1. Mass rearing of *P.solenopsis* on potato sprouts



Plate 2. Emergence of parasitoid *A.bambawalei* from parasitized mealybug colony.



Plate 3. Biology of *P.solenopsis* on mealybug developed potato sprouts



A : *P. solenopsis* on cotton plants



B : *P. solenopsis* on potato sprouts



C : *P. solenopsis* on Hibiscus plants

Plate 4. Maintenance of *P. solenopsis* on different host plants



Plate 5. *A. bambawalei* cocoon on cotton twig



Plate 6. *A. bambawalei* cocoon on *Parthenium* twig



Plate 7. Experimental field of cotton



Plate 8. Cotton shoots infested with *P. solenopsis*

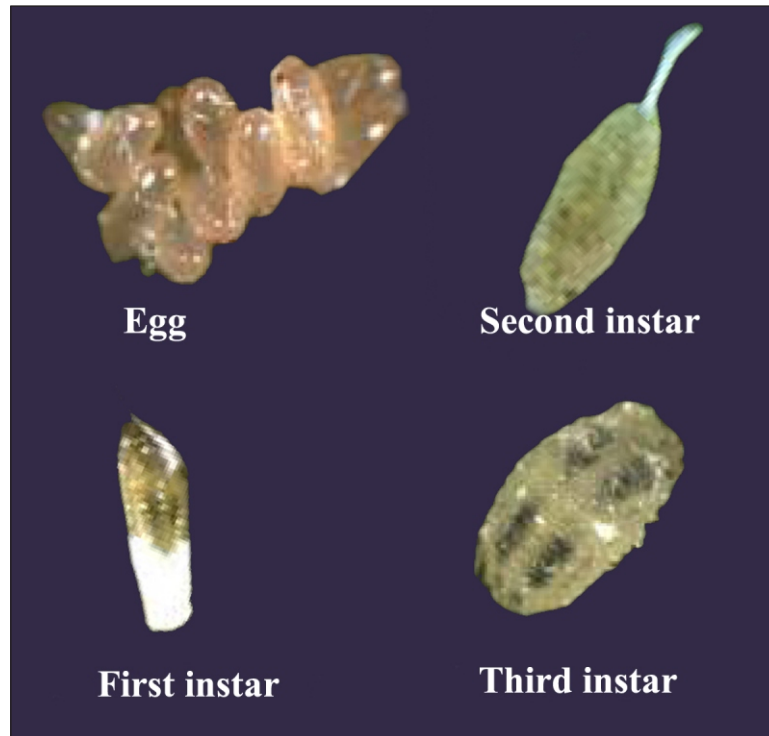


Plate 9. Eggs and different instars of *P. solenopsis*

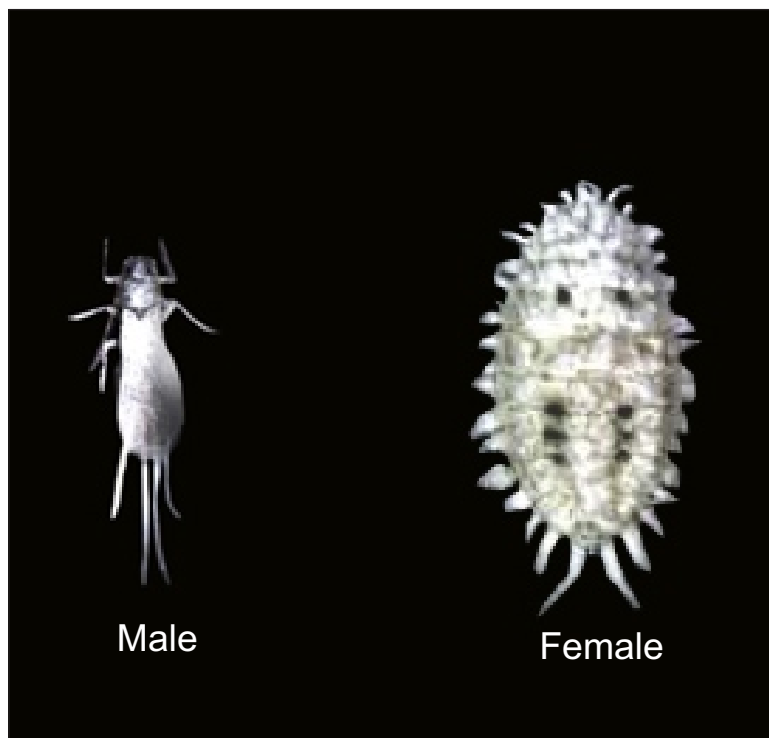


Plate 10. Adult male and female of *P. solenopsis*



Plate No. 11. Cocoon and fully developed adult of *A. bambawalei*



Plate No. 12. Adult male and female of *A. bambawalei*



Hibiscus cannabinus L



Hibiscus rosa sinensis



Gossypium spp.



Parthenium hysterophorus



Euphorbia spp.



Xanthium strumarium L



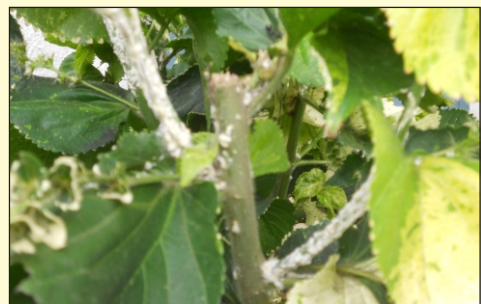
Amaranthus viridis L



Lantana camara L



Lycopersicon esculentum L



Acalypha indica L